OPTICAL PICK-UP APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to an optical pick-up apparatus, an apparatus for recording/reproducing information of an optical information recording medium, and beam expander, and particularly to an optical pick-up apparatus, objective lens and beam expander, by which variations of the spherical aberration can be effectively corrected in a high density optical information recording medium.

Recently, according to the practical use of a short wavelength red semiconductor laser, the development of a DVD (digital versatile disk) which is a high density optical disk whose size is the almost same as a conventional optical disk, that is, a CD (compact disk) which is an optical information recording medium, and whose capacity is greatly increased, is advanced, and in near future, it is presupposed that a higher density next generation optical disk also appears in the

market. In the optical system of the optical information
recording and reproducing apparatus using such the optical
disk as a medium, in order to attain the high densification
of the recording signal, or to reproduce the high density
recording signal, it is required that a spot diameter to
converge the light onto the recording medium through the
objective lens, is reduced. In order to attain this
requirement, there is the actual situation that the reduction
of the wavelength of the laser as the light source or the
increase of the NA of the objective lens are considered.

In this connection, when the reduction of the
wavelength of the laser or the increase of the NA of the
objective lens thus comes to be realized, even an almost
negligible problem in the optical pick-up apparatus
structured by the combination of the comparatively long
wavelength laser and the objective lens of low NA by which
the recording or reproducing of the information is conducted
on the conventional optical disk such as the CD or DVD, it is
more actualized.

A problem actualized in the combination of the
shortening of the wavelength of the laser and the increase of
the NA of the objective lens, is a variation of the spherical
aberration of the optical system due to the temperature and
humidity change. That is, in comparison with a glass lens, a

generally used plastic lens in the optical pick-up apparatus
is easily deformable due to the temperature or humidity
change, and thereby, the refractive index changes. Even in a
variation of the spherical aberration by the change of the
refractive index which is not a problem in the optical system
used in the conventional pick-up apparatus, its amount is not
negligible in the combination the reduction of the wavelength
of the laser and the increase of the NA of the objective
lens, and a problem in which the spot diameter is increased,
is generated. Accordingly, in the optical system employing a
plastic lens, a spherical aberration becomes an important
problem.

Further, another problem in the combination of the
shortening of the wavelength of the laser and the increase of
the NA of the objective lens, is   deviation of a spherical
aberration taking place on the objective lens due to the
slight deviation of wavelength of the light source. In the
semiconductor laser used as a light source in the optical
pickup apparatus, there is a deviation of $\pm$ 10 nm among
actual products of the semiconductor laser. Therefore, if a
semiconductor laser having an wavelength deviating from a
reference wavelength is used as the light source, the
spherical aberration taking place on the objective lens
becomes larger as the numerical aperture becomes lager.

Owing to this, if it is determined that the semiconductor

laser having an wavelength deviating from a reference

wavelength is used as the light source, the selection for the

semiconductor laser to be used as the light source will be

required. As a result, the cost of the semiconductor laser

will be raised.

Further, another problem in the combination of the

shortening of the wavelength of the laser and the increase of

the NA of the objective lens, is deviation of a spherical

aberration of the optical system due to errors in the

thickness of a protective layer (or a transparent substrate)

of the optical disk. Since the spherical aberration caused

by the errors in the thickness of the protective layer occurs

in proportion to fourth power of numerical aperture of the

objective lens, the influence of the errors in the thickness

of the protective layer becomes larger as the numerical

aperture of the objective lens becomes larger, there my be a

fear that recording or reproducing information can not be

conducted stably.

In this connection, for the recording or reproducing of

the information, between the optical disk of the next

generation requiring the combination of the reduction of the

wavelength of the laser and the increase of the NA of the

objective lens, and the conventional optical disk, the

wavelength of the light source and the NA of the objective

lens are greatly different from each other as described

above. Further, in order to suppress the coma greatly

generated due to the tilt of the disk surface from the

surface perpendicular to the optical axis which is

presupposed in the optical disk of the next generation, it is

effective to reduce the transparent substrate thickness,

however, according to that, the transparent substrate

thickness is greatly different from the conventional optical

disk such as a CD. For example, an optical disk proposed for

use in a next future generation comprises a transparent

substrate having a thickness of 0.1 mm which is greatly

different from the thickness of a transparent substrate of CD

or DVD. Therefore, if the information of CD or DVD is

reproduced by the objective lens for use in the next future

generation, a large spherical aberration may be occurred.

Accordingly, at least by using the common objective lens,

without greatly increasing the cost, and by a compact optical

pick-up apparatus, how to record or reproduce the information

by suppressing the spherical aberration for the different

optical information recording medium including the next

generation optical disk, is a problem.

Further, the other problems is a problem of the axial

chromatic aberration caused in the objective lens due to

minute variations of the wavelength of the laser light
source. The change of the reflective index due to the minute
variation of the wavelength of the general optical lens
material is larger as the short wavelength is used.
Therefore, the defocus amount of the focal point caused due
to the minute variation of the wavelength becomes large.
However, as it can be seen from a fact that the depth of
focus of the objective lens is expressed by $k \cdot \lambda/NA^2$ (k is a
proportional constant, λ is the wavelength, and NA is a
numerical aperture of an image side of the objective lens),
the shorter the wavelength of the used light source is, the
smaller the depth of the focus is, and even a few defocus
amount is not allowed. Accordingly, in an optical system
using a short wavelength light source such as the blue purple
semiconductor laser (about 400 nm wavelength) and an
objective lens having a high image side numerical aperture,
in order to prevent a wavelength variation due to the mode
hop phenomenon of the semiconductor laser, or the
deterioration of the wave front aberration due to the high
frequency superimposition, a correction of the axial
chromatic aberration becomes important.

SUMMARY OF THE INVENTION

The present invention has been made in view of the above problems in prior and an object of the present invention is to provide an converging optical system and an optical pickup apparatus capable of correcting efficiently with a simple structure deviation in a spherical aberration occurring in each optical surface in an optical pickup apparatus due to variations in wavelength of a laser light source, changes in temperature and humidity, and errors in the thickness of a transparent base plate (substrate) on an optical information recording medium and in particular, capable of using a plastic lens for the converging optical system.

Further, another object of the present invention is to provide an optical pick-up apparatus by which the axial chromatic aberration due to the mode hopping and HFCS (high frequency superimposition) of the semiconduction laser can be effectively corrected, and its objective lens and the beam expander.

Further, sill another object of the present invention is to provide an optical pick-up apparatus which is provided with the short wavelength laser and the high NA objective lens, and which can record or reproduce the information for the different optical information recording medium.

Hereinafter, examples of means of the present invention to solve the above problems will be exemplified.

(A)   An optical pickup apparatus for conducting recording and/or reproducing information of an optical information recording medium, comprises:

a light source;

a converging optical system to converge light flux emitted from the light source on an information recording plane of the optical information recording medium so as to conduct reproducing and/or recording information of the optical information recording medium, the converging optical system having an objective lens; and

a photo-detector to receive reflected light flux from the information recording plane;

wherein the converging optical system comprises at least a plastic lens and a spherical aberration deviation correcting element to correct deviation of a spherical aberration of the converging optical system and a numerical aperture of the objective lens at an image-side is 0.65 or more.

(B)   An optical information recording medium recording and/or reproducing apparatus for conducting recording and/or reproducing information of an optical information recording medium, comprises:

an optical pickup apparatus comprising:

a light source;

an converging optical system to converge light flux emitted from the light source on an information recording plane of the optical information recording medium so as to conduct reproducing and/or recording information of the optical information recording medium, the converging optical system having an objective lens; and

a photo-detector to receive reflected light flux from the information recording plane;

wherein the converging optical system comprises at least a plastic lens and a spherical aberration deviation correcting element to correct deviation of a spherical aberration of the converging optical system and a numerical aperture of the objective lens at an image-side is 0.65 or more.

(C)   A spherical aberration deviation correcting element for use in an optical information recording medium recording and/or reproducing apparatus, comprises:

a positive lens group having at least one positive lens; and

a negative lens group having at least one negative lens,

wherein a numerical aperture of the objective lens at an
image-side is 0.65 or more,

at least one of the positive lens group and the negative lens
group is movable in a direction of an optical axis and
deviation of a spherical aberration of the optical pickup
apparatus is corrected by moving the at least one of the
positive lens group and the negative lens group in the
direction of an optical axis, and

wherein the spherical aberration deviation correcting element
comprises at least one plastic lens.

(D)   A spherical aberration deviation correcting element for
use in an optical pickup apparatus for recording and/or
reproducing information of the optical information recording
medium, comprises:

        a positive lens group having at least a positive lens;
and

        a negative lens group having at least a negative lens,
wherein at least one of the positive lens group and the
negative lens group is a movable element movable in a
direction of an optical axis and the movable element can
change the slope angle of the marginal ray of an exit light
flux by moving in a direction of the optical axis, and
wherein each positive lens of the spherical aberration
deviation correcting element has Abbe's numbers of 70 or less

or each negative lens of the spherical aberration deviation correcting element has Abbe's numbers of 40 or more and the spherical aberration deviation correcting element comprise at least a diffractive surface having a ring-shaped diffractive structure.

(E)   A spherical aberration deviation correcting element unit for use in an optical information recording medium recording and/or reproducing apparatus, comprising:

a spherical aberration deviation correcting element comprising,

a positive lens group having at least one positive lens; and

a negative lens group having at least one negative lens,

wherein at least one of the positive lens group and the negative lens group is movable in a direction of an optical axis and deviation of a spherical aberration of the optical pickup apparatus is corrected by moving the at least one of the positive lens group and the negative lens group in the direction of an optical axis, and

wherein each positive lens has Abbe's numbers of 70 or less and each negative lens has Abbe's numbers of 40 or more and the spherical aberration deviation correcting element

comprise at least a diffractive surface having a ring-shaped
diffractive structure; and

a moving device to at least one of the positive lens
and the negative lens in a direction of an optical axis.

Further, another preferable means to attain the above
object are exemplified.

(1)   An optical pick-up apparatus comprises a converging
optical system including a light source, and an objective
lens to converge the light flux emitted from the light source
onto the information recording plane (surface) through a
transparent substrate of an optical information recording
medium, and a light detector to light-receive the reflected
light from the optical information recording medium, wherein
the objective lens includes a lens composed of at least one
plastic lens, and because a means for correcting a variation
of the spherical aberration caused by a change of at least
one of the shape and the refractive index of the objective
lens, and by the variation of the (oscillation) wavelength of
the light source, for the environmental change between the
temperature of -30 C to + 85 C, and the humidity of 5 % to 90
%, is provided between the light source and the objective
lens, even when a change of the refractive index is generated
in the objective lens, or even when the change of the
wavelength of the light source is generated, corresponding to

the temperature or humidity change of the environment in
which the optical pick-up apparatus is used, the variation of
the spherical aberration of the objective lens caused due to
them can be effectively suppressed.

In this connection, the objective lens is defined to be
included 'between the light source and the objective lens',
and accordingly, even the diffractive surface provided on the
surface of the objective lens can become a means for
correcting the variation of the spherical aberration in the
present invention.

(2)   An optical pickup apparatus comprises the light source
of the wavelength λ, a converging optical system including
the objective lens to converge the light flux emitted from
the light source onto the information recording plane through
the transparent substrate of the optical information
recording medium, and a light detector for receiving the
reflected light from the optical information recording
medium, wherein a means for correcting the variation of the
spherical aberration is provided between the light source and
the objective lens, and because the means for correcting the
variation of the spherical aberration can correct the
spherical aberration up to 0.2 λrms to less than 0.07 λrms,
for example, the variation of the spherical aberration of the
objective lens caused due to the temperature or humidity

change of the environment in which the optical pick-up

apparatus is used, and/or the minute variation of the

wavelength of the light source, can be effectively

suppressed.

(3)   The optical pick-up apparatus described in (2) is

preferable when the means for correcting the variation of the

spherical aberration can correct the spherical aberration up

to the 0.5 λ rms to not more than 0.07 λrms.

(4)   An optical pick-up apparatus comprises the light

source, a converging optical system including the objective

lens to converge the light flux emitted from the light source

onto the information recording plane through the transparent

substrate of the optical information recording medium, and a

light detector for light-receiving the reflected light from

the optical information recording medium, wherein, because a

means for correcting the variation of the spherical

aberration generated in the objective lens is provided

between the light source and the objective lens, for example,

the variation of the spherical aberration of the objective

lens caused due to the temperature or humidity change of the

environment in which the optical pick-up apparatus is used,

and/or the minute variation of the wavelength of the light

source, can be effectively suppressed.

(5)   Because there is a deviation of about ± 10 nm among the

individual bodies in the wavelength of the semiconductor

laser, in the optical system using the objective lens having

the light source of the short wavelength and the high image

side numerical aperture, when the semiconductor laser

deviated from the wavelength as the reference is used, it

becomes a factor of the performance deterioration of the

apparatus, and it may be necessary to select the

semiconductor laser. An optical pick-up apparatus described

in (5) is an optical pick-up apparatus comprising a light

source, a converging optical system including the objective

lens to converge the light flux emitted from the light source

onto the information recording plane through the transparent

substrate of the optical information recording medium, and a

light detector for light-receiving the reflected light from

the optical information recording medium, wherein, because a

means for correcting the variation of the spherical

aberration generated in the objective lens due to the minute

variation of the wavelength of the light source, is provided

between the light source and the objective lens, the

variation of the spherical aberration of the objective lens

caused when the semiconductor laser deviated from the

wavelength as the reference is used, can be effectively

suppressed, thereby, the selection of the semiconductor laser
is not necessary.

(6)   An optical pick-up apparatus comprises a light source,
a converging optical system including the objective lens to
converge the light flux emitted from the light source onto
the information recording plane through the transparent
substrate of the optical information recording medium, and a
light detector for light-receiving the reflected light from
the optical information recording medium, wherein, because a
means for correcting the variation of the spherical
aberration generated in the conversing optical system due to
the temperature or humidity change is provided between the
light source and the objective lens, thereby, for example,
the variation of the spherical aberration of the objective
lens caused due to the temperature or humidity change of the
environment in which the optical pick-up apparatus is used,
can be effectively suppressed.

(7)   An optical pick-up apparatus comprises a light source,
a converging optical system including the objective lens to
converge the light flux emitted from the light source onto
the information recording plane through the transparent
substrate of the optical information recording medium, and a
light detector for light-receiving the reflected light from
the optical information recording medium, wherein, because a

means for correcting the variation of the spherical

aberration generated in the light conversing optical system

due to the minute variation of the oscillation wavelength of

the light source and the temperature or humidity change is

provided between the light source and the objective lens,

thereby, for example, the variation of the spherical

aberration of the objective lens caused due to the

temperature or humidity change of the environment in which

the optical pick-up apparatus is used, and caused when the

semiconductor laser deviated from the reference wavelength as

the light source is used, can be effectively suppressed.

(8)   The optical pick-up apparatus described in (1) to (7)

is characterized in that a means for correcting the variation

of the spherical aberration includes at least one positive

lens and at least one negative lens, and at least one of them

is a movable element which can move in the optical axis

direction.

(9)   Further, the optical pick-up apparatus described in (1)

to (7) is characterized in that a means for correcting the

variation of the spherical aberration has a positive lens

group having the positive refractive power including at least

one positive lens, and a negative lens group having the

negative refractive power including at least one negative

lens, and at least one lens group of them is a movable element which can move in the optical axis direction.

In the optical pick-up apparatus used the light source of the short wavelength, as described above, the variation of the spherical aberration due to the wavelength variation of the light source or the variation of the spherical aberration due to the temperature and humidity change is large. Particularly, when the objective lens of the high image side numerical aperture (high NA) or the objective lens composed of plastic material is used, the variation is increased. Accordingly, in the optical pick-up apparatus using the light source of the short wavelength, it is particularly necessary to provide a means for correcting the variation of these spherical aberration. When the spherical aberration of the objective lens is varied due to the minute change of the wavelength or the temperature or humidity change, by moving the movable element of a means for correcting the variation of the spherical aberration by an appropriate amount, and by changing the slope angle of the marginal ray of the light flux incident to the objective lens so that the spherical aberration of the wave front formed on the information recording plane is minimum, the variation of the spherical aberration can be corrected.

(10), (11) The optical pick-up apparatus described

respectively in (8) and (9) is characterized in that a means

for correcting the variation of the spherical aberration

satisfies the following expression.

$\nu dP > \nu dN$ (1)

where, νdP: an average of Abbe's numbers of d lines of the

all positive lenses including the positive lens, and

νdN: an average of Abbe's numbers of d lines of the all

negative lenses including the negative lens.

The above expression (1) relates to the correction of

the axial chromatic aberration. Due to the minute variation

of the wavelength of the light source, or the temperature or

humidity change, in the case where the spherical aberration

of the objective lens is varied, when a means for correcting

it is, for example, comprised of an optical element movable

in the optical axis direction by moving, the optical element

by an appropriate amount, the slope angle of the marginal ray

of the light flux incident to the objective lens can be

changed so that the spherical aberration of the objective

lens is minimum. For the axial chromatic aberration of the

objective lens which becomes a problem when the short

wavelength light source is used, it can be corrected when the

means for correcting the variation of the spherical

aberration is constituted by the following structure.

When the material of the positive lens and the negative

lens in the means for correcting the variation of the

spherical aberration is selected so that the above expression

(1) is satisfied, the axial chromatic aberration which has

the inverse sign to the axial chromatic aberration generated

in the objective lens, can be generated. Accordingly,

because the axial chromatic aberration is cancelled with each

other, the wave front when it is focused on the optical

information recording medium, transmitting through the means

for correcting the variation of the spherical aberration and

the objective lens, is in the condition that the axial

chromatic aberration is suppressed to small. When the

diffractive surface is provided to the objective lens and/or

to the means for correcting the variation of the spherical

aberration, because the back focus length of the diffractive

surface decreases as the wavelength increases, the aberration

can be more excellently corrected. In this case, because the

role of the correction of the axial chromatic aberration can

be allotted to the means for correcting the variation of the

spherical aberration and the diffractive surface, when the

means for correcting the variation of the spherical

aberration comprises, for example, the optical element

movable in the optical axis direction, the stroke of such the
optical element can be small.

Further, when the role of the correction the correction
the axial chromatic aberration correction is allotted to the
means for correcting the variation of the spherical
aberration and the diffractive surface, the power of the
diffractive surface can be reduced to small, thereby, the
interval of annular bands of the diffractive surface is
increased, so that the diffraction efficiency of the
diffractive surface can be increased. Accordingly, without
separately providing the means for correcting the variation
of the spherical aberration and the means for correcting the
axial chromatic aberration, even when the variation of the
wavelength or the temperature or humidity change is
generated, a compact optical pick-up apparatus in which the
spherical aberration of the whole optical system and the
axial chromatic aberration is excellently corrected, can be
obtained.

(12), (13) The optical pick-up apparatus described
respectively in (10) and (11) is characterized in that the
vdP and the   vdN satisfy the following expressions.

$$vdP > 55 \qquad\qquad (2)$$

$$vdN < 35 \qquad\qquad (3)$$

When the difference of Abbe's number between the
positive lens and the negative lens is increased, because the
axial chromatic aberration of the inverse sign to that of the
objective lens can be generated largely by the spherical
aberration deriation (variation) correcting element, the
axial chromatic aberration of the optical pick-up optical
system can be more excellently corrected.

(14)   The optical pick-up apparatus described in (8), (10),
or (12) is characterized in that, when the means for
correcting the variation of the spherical aberration is
structured by a positive lens group including the positive
lens and a negative lens group including the negative lens
group, the following expression is realized, and the optical
pick-up apparatus described in the fifteenth aspect is
characterized in that, for the means for correcting the
variation of the spherical aberration, the following
expression is realized.

$$\Delta d \cdot |fP/fN| / \Delta vd \leqq 0.05 \qquad (4)$$

Where,

Δd: the movement amount (mm) of the movable element
when the information is recorded onto or reproduced from one
information recording plane of an arbitrary one optical
information recording medium onto or from which the
information can be recorded or reproduced;

fP: the focal length (mm) of the positive lens group
(where, when the diffractive surface is provided on the
positive lens group, the total focal length in which the
refractive power and diffractive power are combined);

fN: the focal length (mm) of the negative lens group
(where, when the diffractive surface is provided on the
positive lens group, the total focal length in which the
refractive power and diffractive power are combined);

Δvd: in the positive lens group and the negative lens
group, the difference between the maximum value of Abbe's
number of the positive lens and the minimum value of Abbe's
number of the negative lens.

The above expression (4) relates to the paraxial power
of the means for correcting the variation of the spherical
aberration and a balance of the movement amount of the
movable element of the means for correcting the variation of
the spherical aberration. Herein, even though Δvd is small,
when the value of $|fP/fN|$ is made large, the axial chromatic
aberration of the objective lens can be finely corrected, and
when the means for correcting the variation of the spherical
aberration of the objective lens due to the variation of the
wavelength or the temperature or humidity change is
structured by using the optical element displaceable in the
optical axis direction, the stroke of such the optical

element can be suppressed to small, however, there is a
possibility that the effective diameter of the positive lens
group is too large, or the effective diameter of the negative
lens group is too small. Reversely, when the value of the
Δvd is large, even when the value of $|fP/fN|$ is small,
although the axial chromatic aberration of the objective lens
can be finely corrected, the movement amount of the movable
element of the means for correcting the variation of the
spherical aberration necessary for correction of the
spherical aberration becomes large, therefore, there is a
possibility that the size of the optical system becomes
large. Accordingly, when the value of $\Delta d \cdot |fP/fN|/ \Delta vd$ is
made to satisfy the above expression (4), the balance of them
can be attained. hat is, an axial chromatic aberration can be
corrected well and further a compact optical system can be
obtained.

(16),(17)   The optical pick-up apparatus described
respectively in ((8), (10) or (12)) and ((9), (11) or (13))
can conduct the recording and/or reproducing of the
information for at least 2 kinds of optical information
recording media, and because the means for correcting the
variation of the spherical aberration changes the slope angle
of marginal ray of the light flux incident to the objective
lens for at least 2 kinds of optical information recording

media whose transparent substrate thickness are different

from each other, corresponding to each transparent substrate

thickness, the difference of the spherical aberration due to

the difference of the transparent substrate thickness is

corrected, and because the variation of the spherical

aberration generated when the recording or the reproducing is

conducted on each optical information recording medium, can

be finely corrected, the fine wave front can always be formed

on the information recording plane.

(18),(19)   The optical pick-up apparatus described

respectively in ((8), (10) or (10)) and ((9), (11) or (13) to

(15)) can conduct the recording and/or reproducing of the

information on the optical information recording medium in

which a plurality of the transparent substrates and the

information recording planes are laminated in order from the

front surface side of the optical information recording

medium, and when the means for correcting the variation of

the spherical aberration respectively conducts the light

converging on each information recording plane, because it

changes the slope angle of the marginal ray of the incident

light flux of the objective lens corresponding to the

information recording plane, the difference of the spherical

aberration due to the difference in the thickness is

corrected, and because the variation of the spherical

aberration generated when the recording or reproducing is
conducted on the respective information recording plane, is
finely corrected, the fine wave front can be respectively
formed on the information recording plane for each
information recording plane. As described above, the
recording or reproducing of the information can be finely
conducted also on the optical information recording medium
having 2 layer- or the more layer-information recording
planes. For example, when the objective lens is moved in the
optical axis direction, the focusing can be conducted on
desired one information recording plane, and in this case,
because the spherical aberration varied due to the difference
of the thickness up to the information recording plane is
mainly 3 order spherical aberration, when the movable element
of the means for correcting the variation of the spherical
aberration is moved along the optical axis direction, the
variation of the spherical aberration can be finely
corrected. Accordingly, the recording or reproducing of the
information of 2 times or the more, can be conducted on the
surface of the single side of the optical information
recording medium.

(20),(21)   The optical pick-up apparatus described
respectively in (16) and (17) is characterized in that, in
the case where two kinds of transparent substrate thickness

of the optical information recording medium are respectively

a and b (a < b), when the information is recorded or

reproduced on the optical information recording medium of the

transparent substrate thickness a, the interval between the

negative lens and the positive lens is increased more than

the case where the information is recorded or reproduced on

the optical information recording medium of the transparent

substrate thickness b.

(22) The optical pick-up apparatus described in (16), (18),

or (20) is characterized in that, when the means for

correcting the variation of the spherical aberration is

structured by the positive lens group including the positive

lens and the negative lens group including the negative lens,

the following expression is satisfied.

(23) The optical pick-up apparatus described in (17), (19)

or (21) is characterized in that the following expression is

satisfied.

$$|fP/fN| \geqq 1.3 \qquad (5)$$

Where,

fP: the focal length (mm) of the positive lens group (where,

when the diffractive surface is provided on the positive lens

group, the whole focal length in which the refractive

(refracting) power and diffractive (diffracting) power are

totaled); and fN: the focal length (mm) of the negative lens

group (where, when the diffractive surface is provided on the negative lens group, the whole focal length in which the refracting power and diffracting power are totaled).

The above expression (5) relates to the relationship of the paraxial power of the means for correcting the variation of the spherical aberration. In the case where the objective lens is corrected so that the aberration is minimum under the combination of the transparent substrate having the specific thickness, when the thickness of the transparent substrate is changed, by moving the movable element in the means for correcting the variation of the spherical aberration, it is necessary that the slope angle of the marginal ray of the incident light flux is changed so that the spherical aberration of the objective lens is minimum to the thickness. Accordingly, when the paraxial power of the means for correcting the variation of the spherical aberration is selected so that the above expression (5) is satisfied, the stroke of the movable element is decreased, thereby the totally compact optical system can be obtained.

(24) The optical pick-up apparatus described in one of (8) to (23) is characterized in that the means for correcting the variation of the spherical aberration has a transfer apparatus to transfer the movable element along the optical

axis corresponding to the variation of the spherical aberration.

(25)   The optical pick-up apparatus described in one of (8) to (24) is characterized in that the movable element is formed of the material of specific gravity not larger than 2.0. Thereby, the burden of the movable device can be lightened.

(26)   The optical pick-up apparatus described in one of (8) to (25) is characterized in that at least one of the positive lens and the negative lens is formed of the plastic material. Particularly, when the movable element of the spherical aberration correction means is made of the plastic material, the burden onto the transfer apparatus can be lightened, and high speed tracking becomes possible. Further, when the components on which the diffractive surface or aspherical surface is provided, are formed of the plastic material, diffractive surface or aspherical surface can be easily added.

(27)   The optical pick-up apparatus described in one (8) to (25) is characterized in that the movable element is formed of the plastic material. Thereby, the weight reduction of the optical system can be attained, thereby, the burden of the movable device can be lightened. Further, the diffractive structure can be easily added.

(28)   The optical pick-up apparatus described in one of (8)
to (27) is characterized in that at least one of the positive
lens and the negative lens has the aspherical surface on at
least one surface, and an optical pick-up apparatus described
in the 29th aspect is characterized in that it has the
aspherical surface on at least one surface of the movable
element. By providing the aspherical surface, the means for
correcting the variation of the spherical aberration can
obtain the good performance optical system by the aberration
correction action of the aspherical surface. Particularly,
when the aspherical surface is provided on the movable
element, the deterioration of the wave front aberration at
the time of the decenter of movable element can be prevented.
(30)   The optical pick-up apparatus described in one of (8)
to (29) is characterized in that the means for correcting the
variation of the spherical aberration is formed of the
material whose saturate water absorption is not larger than
0. 5 %.
(31)   The optical pick-up apparatus described in one of (8)
to (30) is characterized in that the means for correcting the
variation of the spherical aberration is formed of the
material whose internal transmittance at the thickness of 3
mm, is not smaller than 85 % to the light of the oscillation
wavelength of the light source.

(32) The optical pick-up apparatus described in one (8) to
(31) is characterized in that the means for correcting the
variation of the spherical aberration is structured by one
positive lens and one negative lens.

(33) In the optical pick-up apparatus described in one of
(8) to (32), because the means for correcting the variation
of the spherical aberration includes the optical element
provided with the diffractive surface having the ring shaped
diffractive structure, the axial chromatic aberration can be
effectively corrected by using such the diffractive surface,
therefore, it is not necessary that the optical element for
the axial chromatic diffraction correction is newly provided,
thereby, the low cost and space saving can be attained. In
this connection, the optical element provided with the
diffractive surface includes one lens of the lens group, and
accordingly, it includes one side of the positive lens group
or the negative lens group. Further, it also includes the
optical element separately provided other than those lenses.

(34) The optical pick-up apparatus described in one of (1)
to (7) is characterized in that the means for correcting the
variation of the spherical aberration has the element whose
refractive index distribution can be changed. As such the
element, there is an element such as the element SE using the
liquid crystal which will be described later referring to

Fig. 24 and Fig. 24, however, the element is not limited to
this.

(35) An optical pick-up element comprises the light source;
the converging optical system including the objective lens to
light converge the light flux emitted from the light source
onto the information recording plane through the transparent
substrate of the optical information recording medium; and
the light detector to light receive the reflected light from
the optical information recording medium. Wherein, because a
means for correcting the variation of the spherical
aberration generated in the objective lens, and the axial
chromatic aberration generated in the objective lens is
provided between the light source and the objective lens, the
variation of the spherical aberration of the objective lens
generated when the wavelength of the semiconductor laser as
the light source is minutely varied, can be effectively
suppressed. Further, even when the refractive index change
is generated in the objective lens corresponding to the
environmental temperature or humidity change, the variation
of the spherical aberration of the objective lens due to
that, can be effectively suppressed. Further, because the
axial chromatic aberration generated in the objective lens
can be effectively corrected, even when the instantaneous
mode hopping of the oscillation wavelength to which the

spherical aberration correction means or focusing of the

objective lens can not follow is generated, a fine wave front

can be always formed on the information recording plane.

(36) the optical pick-up apparatus described in (35) is

characterized in that the means for correcting the variation

of the spherical aberration and the axial chromatic

aberration includes at least one positive lens and at least

one negative lens, and at least one of them is a movable

element which can be transferred in the optical axis

direction.

(37) Further, the optical pick-up apparatus described in

(35) is characterized in that the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration includes the positive lens group having the

positive diffracting power including one positive lens and

the negative lens group having the negative diffracting power

including one negative lens, and at least one lens group of

them is a movable element which can be transferred in the

optical axis direction.

In the optical pick-up apparatus used for the light

source of the short wavelength, as described above, the

variation of the wavelength of the light source or the

variation of the spherical aberration due to the temperature

or humidity change is large. Particularly, when the

objective lens of the high image side numerical aperture
(high NA) or the objective lens formed of the plastic
material is used, the variation is increased. Accordingly,
in the optical pick-up apparatus using the light source of
the short wavelength, it is particularly necessary that the
means for correcting the variation of these spherical
aberration is provided. When the spherical aberration of the
objective lens is varied due to the minute variation of the
wavelength of the light source or the temperature or humidity
change, by moving the movable element of the correction means
for the variation of the spherical aberration and the axial
chromatic aberration by an appropriate amount, when the
divergent angle of the light flux (slope angle of the
marginal ray of the incident light flux) incident to the
objective lens is changed so that the wave front aberration
of the wave front formed on the information recording medium
is minimum, the variation of the spherical aberration can be
corrected.

(38),(39)   The optical pick-up apparatus described
respectively in (36) and (37) is characterized in that the
means for correcting the variation of the spherical
aberration and the axial chromatic aberration satisfies the
above expression (1).

The above expression (1) relates to the correction of
the axial chromatic aberration. In the case where the
spherical aberration of the objective lens is varied due to
the minute variation or the temperature or humidity change,
when the means for correcting this is structured by using the
optical element transferable, for example, in the optical
axis direction, the optical element is moved by an
appropriate amount, and slope angle of marginal ray of the
light flux incident to the objective lens can be changed so
that the spherical aberration of the objective lens is
minimum. The axial chromatic aberration of the objective
lens which is a problem when the light source of the short
wavelength is used, can be corrected when a means for
correcting the variation of the spherical aberration and the
axial chromatic aberration has the following structure.

When the material of the positive lens and the negative
lens in the means for correcting the variation of the
spherical aberration and the axial chromatic aberration is
selected so as to satisfy the expression (1), the axial
chromatic aberration of inversal sign to the axial chromatic
aberration generated in the objective lens can be generated.
Accordingly, because the chromatic aberrations are cancelled
with each other, the wave front when it is focused onto the
optical information recording medium through the means for

correcting the variation of the spherical aberration and the
axial chromatic aberration and the objective lens, is in the
condition that the axial chromatic aberration is suppressed
to small. When the diffractive surface is provided to the
objective lens and/or the means for correcting the variation
of spherical aberration and the axial chromatic aberration,
because the back focus length of the diffractive surface
decrease as the wavelength increases, the aberration can be
more finely corrected. In this case, because the role of the
axial chromatic correction can be allotted to the means for
correcting the variation of the spherical aberration and the
axial chromatic aberration and to the diffractive surface,
when, for example, the means for correcting the variation of
the spherical aberration and the axial chromatic aberration
is structured by using the optical element transferable in
the optical axis direction, the stroke of such the optical
element is enough to be short.

Further, when the role of the correction the axial
chromatic correction can be allotted to the means for
correcting the variation of the spherical aberration and the
axial chromatic aberration and to the diffractive surface,
the power of the diffractive surface can be reduced, thereby,
the interval of annular bands of the diffractive surface is
increased, so that the diffraction efficiency of the

diffractive surface can be increased. Accordingly, it is not necessary that the means for correcting the variation of the spherical aberration and the means for correcting the axial chromatic aberration are separately provided, and even when the wavelength variation or the temperature or humidity change is generated, the compact optical pick-up apparatus by which the spherical aberration of the whole optical system and the axial chromatic aberration are finely corrected, can be obtained.

(40),(41)   The optical pick-up apparatus described respectively in (38) and (39) is characterized in that the vdP and the vdN satisfy the above expressions (2) and (3).

When the difference between Abbe's numbers of the positive lens and the negative lens is increased, because the axial chromatic aberration of the inverse sign to that of the objective lens can be generated largely by the spherical aberration deriation correcting element the axial chromatic aberration of the optical pick-up optical system can be more finely corrected.

(42) The optical pick-up apparatus described in (36), (38) or (40) is characterized in that, when the means for correcting the variation of the spherical aberration and the axial chromatic aberration is structured by the positive lens group including the positive lens and the negative lens group

including the negative lens, the above expression (4)is

realized.

(43)   The optical pick-up apparatus described in (37), (39)

or (41) is characterized in that the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration satisfies the above expression (4).

The above expression (4) relates to the correction

amount of the axial chromatic aberration of the objective

lens, the paraxial power of the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration, and a balance of the movement amount of the

movable element of the means for correcting the variation of

the spherical aberration and the axial chromatic aberration.

Herein, even when the value of Δvd is small, when the value

of $|fP/fN|$ is increased, the axial chromatic aberration of

the objective lens can be finely corrected, and when the

means for correcting the variation of the spherical

aberration and the axial chromatic aberration by which the

variation of the spherical aberration of the objective lens

due to the wavelength variation or the temperature or

humidity change can be corrected, is structured by the

optical element movable in the optical axis direction, the

stroke of such the optical element can be suppressed to

small, however, there is a possibility that the effective

diameter of the positive lens group becomes too large, or the

effective diameter of the negative lens group becomes too

small. Reversely, when the value of Δνd is increased, even

when the value of $|fP/fN|$ is small, the axial chromatic

aberration of the objective lens can be finely corrected,

however, the movement amount of the movable element of the

means for correcting the variation of the spherical

aberration and the axial chromatic aberration is increased,

therefore, there is a possibility that the size of the

optical system becomes large. Accordingly, when the value of

Δd · $|fP/fN|$/Δνd is made to satisfy the above expression (5),

the balance of them can be attained. That is, an axial

chromatic aberration can be corrected well and further a

compact optical system can be obtained.

(44) The optical pick-up apparatus described in (36), (38)

or (40) is characterized in that, when the means for

correcting the variation of the spherical aberration and the

axial chromatic aberration is structured by the positive lens

group including the positive lens and the negative lens group

including the negative lens, the next expression is realized.

(45) The optical pick-up apparatus described in (37), (39),

or (41) to (43) is characterized in that the means for

correcting the variation of the spherical aberration and the
axial chromatic aberration satisfies the next expression.

$$\Delta d \cdot |fP/fN| \leqq 0.50 \qquad (6)$$

Where, Δd: the movement amount (mm) of the movable element
when the information is recorded onto or reproduced from one
information recording plane of an arbitrary one optical
information recording medium onto or from which the
information can be recorded or reproduced; fP: the focal
length (mm) of the positive lens group (where, when the
diffractive surface is provided on the positive lens group,
the whole focal length in which the refracting power and
diffracting power are totaled); fN: the focal length (mm) of
the negative lens group (where, when the diffractive surface
is provided on the positive lens group, the whole focal
length in which the refracting power and diffracting power
are totaled); and Δvd: in the positive lens group and the
negative lens group, the difference between the maximum value
of Abbe's number of the positive lens and the minimum value
of Abbe's number of the negative lens.

Incidentally, it may be preferable that Δd is defied as
followed: Δd is a shifting distance necessary to correct the
spherical aberration deviation lower than λ rms where the
spherical aberration deviation occurs when the temperature

raises + 30 °C above the reference temperature (preferably,

15 to 35 °C).

The above expression (6) relates to the correction

amount of the axial chromatic aberration of the objective

lens, the paraxial power of the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration, and a balance of the movement amount of the

movable element of the means for correcting the variation of

the spherical aberration and the axial chromatic aberration.

When the refracting power as the refractive lens of the means

for correcting the variation of the spherical aberration and

the axial chromatic aberration, and the diffracting power of

the diffractive surface added to the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration, are appropriately combined, the axial chromatic

aberration of the objective lens can be corrected. At this

time, in the case where the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration, by which the variation of the oscillation

wavelength of the light source and the variation of the

spherical aberration of the objective lens due to the

temperature or humidity change are corrected, is structured

by using the optical element transferable in the optical axis

direction, when the stroke of such the optical element is too

large, the problem that the spherical aberration can not be

finely corrected, is generated. Accordingly, in the above

expression (6), when the value of $\Delta d \cdot |fP/fN|$ is made not

larger than 0.50, the balance of the correction of the axial

chromatic aberration and the correction of the spherical

aberration of the objective lens can be finely maintained.

(46),(47)   In the optical pick-up apparatus described

respectively in ((36), (38) or (40)) and ((37), (39), or (41)

to (45)), the recording and/or reproducing of the information

can be conducted on two kinds of optical information

recording media, and because the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration changes the slope angle of the marginal ray of the

light flux incident to the objective lens to at least 2 kinds

of optical information recording medium whose transparent

substrate thickness are different from each other,

corresponding to the respective transparent substrate

thickness, the difference of the spherical aberrations due to

the difference of the transparent substrate thickness is

corrected, and further, because the variation of the

spherical aberration generated when the recording or

reproducing is conducted on the respective optical

information recording medium, is finely corrected, the fine

wave front can be always formed on the information recording

plane.

(48),(49)   In the optical pick-up apparatus described

respectively in ((36), (38) or (40)) and ((37), (39), or (41)

to (45)), the recording and/or reproducing of the information

can be conducted on the optical information recording medium

in which a plurality of transparent substrates and the

information recording layers are laminated in the order from

the front surface side of the optical information recording

medium, and when the means for correcting the variation of

the spherical aberration and the axial chromatic aberration

respectively converges the light onto respective information

recording planes, corresponding to the information recording

layer, because the slope angle of the marginal ray of the

light flux incident to the objective lens is changed, the

difference of the spherical aberrations due to the difference

of the thickness up to the information recording plane is

corrected, and further, because the variation of the

spherical aberration generated when the recording or

reproducing is conducted on the respective optical

information recording medium, is finely corrected, the fine

wave front can be always formed respectively on the

information recording plane for each of respective

information recording plane. As described above, even for

the optical information recording medium on whose single side
surface the 2 layers or the more information recording planes
are provided, the recording or reproducing of the information
can be finely conducted. For example, when the objective
lens is moved in the optical axis direction, the focusing can
be obtained on one information recording plane, and in this
case, because the spherical aberration varied by the
difference of the thickness up to the information recording
plane is mainly the tertiary order spherical aberration, when
the movable element of the means for correcting the variation
of the spherical aberration and the axial chromatic
aberration is transferred along the optical axis direction,
the variation of the spherical aberration can be finely
corrected. Accordingly, the recording or reproducing of the
2 times or more information can be conducted on the single
side surface of the information recording medium.

(50),(51)   The optical pick-up apparatus described
respectively in (46) and (47) is characterized in that, when
the transparent substrate thickness of the 2 kinds of optical
information recording media are respectively a and b (a < b),
in the case where the recording or reproducing the
information is conducted on the information recording plane
of the optical information recording medium of the
transparent substrate thickness a, the interval between the

negative lens and the positive lens is more increased than

the case where the recording or reproducing of the

information is conducted on the information recording plane

of the optical information recording medium of the

transparent substrate thickness b.

(52) The optical pick-up apparatus described in (46), (48)

or (50) is characterized in that, when the means for

correcting the variation of the spherical aberration and the

axial chromatic aberration is structured by the positive lens

group including the positive lens and the negative lens group

including the negative lens, the above expression (5) is

satisfied.

(53) The optical pick-up apparatus described in (47), (49)

or (51) is characterized in that the above expression (5) is

satisfied.

The above expression (5) relates to the relationship of

the paraxial power of the means for correcting the variation

of the spherical aberration and the axial chromatic

aberration. In the case where the objective lens is

corrected so that the aberration is minimum under the

combination of the transparent substrate having the specific

thickness, when the thickness of the transparent substrate is

changed, by moving the movable element in the means for

correcting the variation of the spherical aberration and the

axial chromatic aberration, it is necessary that slope angle

of the marginal ray of the incident light flux is changed so

that the spherical aberration of the objective lens is

minimum to the thickness. Accordingly, when the paraxial

power of the means for correcting the variation of the

spherical aberration and the axial chromatic aberration is

selected so that the above expression (5) is satisfied, the

stroke of the movable element is decreased, thereby the

totally compact optical system can be obtained.

(54) The optical pick-up apparatus described in one of (36)

to (53) is characterized in that the means for correcting the

variation of the spherical aberration and the axial chromatic

aberration has the transfer apparatus to transfer the movable

element along the optical axis corresponding to the variation

of the spherical aberration.

(55) The optical pick-up apparatus described in one of (36)

to (54) is characterized in that the movable element is

formed of the material whose density is not larger than 2.0.

Thereby, the burden of the movable element onto the transfer

apparatus can be lightened.

(56) The optical pick-up apparatus described in one of (36)

to (55) is characterized in that at least one of the positive

lens and the negative lens is formed of the plastic material.

Particularly, when the movable element of the means for

correcting the variation of the spherical aberration and the

axial chromatic aberration is made of the plastic material,

the burden onto the transfer apparatus can be lightened, and

high speed tracking becomes possible. Further, when the

components on which the diffractive surface or aspherical

surface is provided, are formed of the plastic material,

diffractive surface on aspherical surface can be easily

added.

(57) The optical pick-up apparatus described in one of (36)

to (55) is characterized in that the movable element is

formed of the plastic material. Thereby, the weight

reduction of the optical system can be attained, thereby, the

burden of the movable device can be lightened. Further, the

diffractive structure can be easily added.

(58) The optical pick-up apparatus described in one of (36)

to (57) is characterized in that at least one of the positive

lens and the negative lens has the aspherical surface on at

least one surface, and an optical pick-up apparatus described

in the 59th aspect is characterized in that it has the

aspherical surface on at least one surface of the movable

element. By providing the aspherical surface, the means for

correcting the variation of the spherical aberration and the

axial chromatic aberration can obtain the good performance

optical system by the aberration correction action of the

aspherical surface. Particularly, when the aspherical surface is provided on the movable element, the deterioration of the wave front aberration at the time of the decenter of movable element can be prevented.

(60) The optical pick-up apparatus described in one of (36) to (59) is characterized in that the means for correcting the variation of the spherical aberration and the axial chromatic aberration is formed of the material whose saturate water absorption is not larger than 0. 5 %.

(61) The optical pick-up apparatus described in one of (36) to (60) is characterized in that the means for correcting the variation of the spherical aberration and the axial chromatic aberration is formed of the material whose internal transmittance at the thickness of 3 mm, is not smaller than 85 % to the light of the oscillation wavelength of the light source.

(62) The optical pick-up apparatus described in one of (36) to (61) is characterized in that the means for correcting the variation of the spherical aberration and the axial chromatic aberration is structured by one positive lens and one negative lens.

(63) In the optical pick-up apparatus described in one of (36) to (62), because, when the means for correcting the variation of the spherical aberration and the axial chromatic

aberration includes the optical element provided with the
diffractive surface having the ring shaped diffractive
structure, the axial chromatic aberration can be effectively
corrected by using such the diffractive surface, therefore,
it is not necessary that the optical element for the axial
chromatic diffraction correction is newly provided, thereby,
the low cost and space saving can be attained. In this
connection, the optical element provided with the diffractive
surface includes one lens of the lens group, and accordingly,
it includes one side of the positive lens group or the
negative lens group. Further, it also includes the optical
element separately provided other than those lenses.

(64) The optical pick-up apparatus described in (35) is
characterized in that the means for correcting the variation
of the spherical aberration and the axial chromatic
aberration has the element whose refractive index
distribution can be changed.

(65) The optical pick-up apparatus described in (64) is
characterized in that the means for correcting the variation
of the spherical aberration and the axial chromatic
aberration has a coupling lens provided with the function for
correcting the axial chromatic aberration of the objective
lens.

(66)   The optical pick-up apparatus described in one of (1)
to (65) is characterized in that it has the optical element
provided with the diffractive surface having the ring shaped
diffractive structure.

(67)   The optical pick-up apparatus described (66) is
characterized in that the objective lens is the optical
element(optical element provided with the diffractive surface
having the ring band shaped diffractive structure).

(68)   The optical pick-up apparatus described in (67) is
characterized in that at least one surface of the objective
lens is an aspherical single objective lens, and satisfies
the following expression.

$$5.0 \leqq fD/f \leqq 40.0 \qquad\qquad (7)$$

Where, fD: when the diffractive structure of the objective
lens is expressed by the optical path difference function
defined by $\Phi b = b_2h^2 + b_4h^4 + b_6h^6 + \ldots$ (herein, h is the height
(mm) from the optical axis, and b_2, b_4, b_6, … are the optical
path difference function coefficients of the second order,
fourth order, sixth order, …), the focal length, which is
defined by $fD = 1/(-2 \cdot b_2)$, at the wavelength of the light
source by only the diffractive structure of the objective
lens, and f: the focal length at the oscillation wavelength
of the light source of the whole objective lens in which the

refractive power of the objective lens and the diffractive

power are combined with together.

(68) An optical pick-up apparatus relates to the correction

of the axial chromatic aberration of the objective lens used

for the optical pick-up apparatus by which the variation of

the spherical aberration can be finely corrected. When the

short wavelength laser light source of the wavelength of

about 400 nm and the objective lens having the high image

side numerical aperture of about NA 0.85 are used, from the

above reason, the correction of the axial chromatic

aberration generated in the objective lens can become a

important problem. This problem is solved by providing the

diffractive structure having the focal length satisfying the

above expression (7) on the objective lens. Because this

diffractive structure has the wavelength characteristic which

changes in the direction in which the back focus becomes

short, when the refracting power as the refractive lens and

the diffracting power as the diffractive lens are

appropriately selected so as to satisfy the above expression

(7), the axial chromatic aberration generated in the

objective lens can be corrected. It can be conducted that

the value of the fD/f is not smaller than the lower limit of

the above expression (7) and the axial chromatic aberration

of the objective lens is not too excessively corrected, and

the value of the fD/f is not larger than the upper limit of

the above expression (7) and the axial chromatic aberration

of the objective lens is not too insufficiently corrected.

Further, when the axial chromatic aberration of the objective

lens is in the excessively corrected condition, the axial

chromatic aberration generated in each optical element

included in the converging optical system can be just

cancelled by the objective lens, which is preferable.

(69)   The optical pick-up apparatus described in one of (33),

(63), one of (66) to (68) is characterized in that the

diffractive structure is structured so that the n-order

diffraction light (herein, n is an integer other than -1, 0

and +1) whose diffraction light amount is larger than that of

any other order diffraction light, in the diffraction light

generated by the diffractive structure, is generated, and for

the recording and/or reproducing of the information to the

optical information recording medium, the n-order diffraction

light can be light converged onto the information recording

plane of the information recording medium.

The optical pick-up apparatus described in (69)

particularly relates to the optical system used in the

optical pick-up apparatus in which the recording or

reproducing of the information by using the higher order

diffraction light than 2-order generated in the diffractive

structure is conduced on the optical information recording
medium. When the n-order diffraction light is used, as
compared to the case where +1 order or -1 order diffraction
light is used, because the ring band interval (ring band
pitch) of the diffractive structure can be increased to about
n times and the ring band number can be made to about 1/n,
the lens molding die for adding the diffractive structure can
be easily produced, and the processing time of the molding
die can be reduced, and the lowering of the diffraction
efficiency due to the processing · production error can be
prevented.

(70) The optical pick-up apparatus described in one of (8)
to (33) is characterized in that, in the means having the
optical element provided with the diffractive surface having
the ring band shaped diffractive structure and for correcting
the variation of the spherical aberration, respective Abbe's
numbers of all positive lenses including the positive lens
are not larger than 70.0, or respective Abbe's numbers of all
negative lenses including the negative lens are not smaller
than 40.0.

(71) The optical pick-up apparatus described in one of (36)
to (63) is characterized in that, in the means having the
optical element provided with the diffractive surface having
the ring band shaped diffractive structure and for correcting

the variation of the spherical aberration and the axial chromatic aberration, respective Abbe's numbers of all positive lenses including the positive lens are not larger than 70.0, or respective Abbe's numbers of all negative lenses including the negative lens are not smaller than 40.0.

The optical pick-up apparatus described in (70) relates to a preferable structure of the means for correcting the variation of the spherical aberration by which the axial chromatic aberration generated in the objective lens can be corrected, and the optical pick-up apparatus described in (71) relates to a preferable structure of the means for correcting the variation of the spherical aberration and the axial chromatic aberration by which the axial chromatic aberration generated in the objective lens can be corrected. When Abbe's number of the positive lens structuring the means for correcting the variation of the spherical aberration or the means for correcting the variation of the spherical aberration and the axial chromatic aberration is not larger than 70.0 or Abbe's number of the negative lens structuring the means is not smaller than 40.0, the axial chromatic aberration generated in the objective lens is apt to be insufficient correction. In this case, when the diffractive surface having the diffractive structure having the wavelength characteristic so that the back focus of the

objective lens becomes short when the oscillation wavelength
of the light source is minutely varied to the long wavelength
side is provided on at least one surface of the component of
the means for correcting the variation of the spherical
aberration or the means for correcting the variation of the
spherical aberration and the axial chromatic aberration, the
axial chromatic aberration of the objective lens can be
finely corrected. Further, when, on this diffractive
surface, the spherical aberration characteristic in which the
spherical aberration of the objective lens becomes
insufficient correction when the oscillation wavelength of
the light source is minutely varied to the long wavelength
side, is provided, the spherical aberration generated when
the oscillation wavelength of the light source is minutely
varied to the long wavelength side, can also be corrected.
Further, when Abbe's number of the positive lens is not
larger than 70.0, the strength is excellent, the production
is easy, and also for the anti-environment, it is good. On
the one hand, when Abbe's number of the negative lens is not
smaller than 40.0, the penetrability for the light of short
wavelength is excellent. For both the positive lens and the
negative lens, it is preferable that Abbe's numbers are not
smaller than 40.0 and not larger than 70.0.

(72)   The optical pick-up apparatus described in (70) is
characterized in that the means for correcting the variation
of the spherical aberration, and further, (73) the optical
pick-up apparatus described in (71) is characterized in that
the means for correcting the variation of the spherical
aberration and the axial chromatic aberration is,
respectively, when the paraxial power in the oscillation
wavelength of the light source is P1, the paraxial power in
the wavelength which is 10 nm shorter than the oscillation
wavelength is P2, and the paraxial power in the wavelength
which is 10 nm longer than the oscillation wavelength is P3,
the following expression is satisfied.

$$P2 < P1 < P3 \qquad\qquad (8)$$

According to this, the role for correcting the axial
chromatic aberration generated in the optical element such as
the objective lens or the coupling lens can be allotted to a
means for correcting the variation of the spherical
aberration, or the means for correcting the variation of the
spherical aberration and the axial chromatic aberration.
That is, in the means itself for correcting the variation of
the spherical aberration by the diffractive structure, or in
the means itself for correcting the variation of the
spherical aberration and the axial chromatic aberration, the
axial chromatic aberration is excessively corrected and by

generating the axial chromatic aberration whose polarity is
reverse to the axial chromatic aberration generated in the
optical element such as the objective lens or coupling lens,
the axial chromatic aberration generated in the optical
element such as the objective lens or coupling lens can be
corrected.

(74) The optical pick-up apparatus described in (33), (63),
or one of (66) to (73) is characterized in that the
diffractive surface has the function to suppress the axial
chromatic aberration generated in the objective lens with
respect to the minute variation of the oscillation wavelength
of the light source.

(75) The optical pick-up apparatus described in (33), (63),
or one of (66) to (74) is characterized in that, when the
oscillation wavelength of the light source is minutely varied
to the long wavelength side, the diffractive surface has the
wavelength characteristic so that the back focus of the
objective lens becomes short. According to this, the axial
chromatic aberration can be finely corrected. Particularly,
when the axial chromatic aberration generated in the
objective lens is corrected by providing the diffractive
surface on the coupling lens and/or the objective lens, even
when the instantaneous wavelength change, such as the mode
hop, on which the spherical aberration deviation means or the

focusing of objective lens can not follow, is generated, the

spot diameter is not increased, and the stable recording or

reproducing of the information can be conducted.

(76)   The optical pick-up apparatus described in (33), (63),

or one of (66) to (75) is characterized in that, when the

oscillation wavelength of the light source is minutely varied

to the long wavelength side, the diffractive surface has the

spherical aberration characteristic in which the spherical

aberration of the objective lens is changed to the direction

of the insufficient correction.   Thereby, the spherical

aberration generated when the oscillation wavelength of the

light source is minutely varied to the long wavelength side,

can be finely corrected.

(77)   The optical pick-up apparatus described in one of (1)

to (65) is characterized in that the light source has at

least 2 light sources of the light source of the oscillation

wavelength $\lambda 1$ and the light source of the oscillation

wavelength $\lambda 2$ ($\lambda 1 < \lambda 2$), and the converging optical system

can converge the first light flux from the light source of

the oscillation wavelength $\lambda 1$ onto the information recording

plane of the first optical information recording medium of

the transparent substrate thickness t1 in the condition not

larger than the wave front aberration 0.07 $\lambda 1$ rpm within a

predetermined numerical aperture on the image side of the

objective lens necessary for the recording or reproducing of

the information, and can converge the second light flux

emitted from the light source of the oscillation wavelength

$\lambda 2$ onto the information recording plane of the second optical

information recording medium of the transparent substrate

thickness t2 (t1 $\leqq$ t2) in the condition not larger than the

wave front aberration 0.07 $\lambda 2$ rpm within a predetermined

numerical aperture on the image side of the objective lens

necessary for the recording or reproducing of the

information.

For example, in the case where recording or reproducing

the information is conducted onto the optical information

recording media of the different transparent substrate

thickness, by using the short wavelength light source such as

the blue purple semiconductor laser, when the design work is

conducted so that the spherical aberration correction of the

objective lens becomes optimum on the one side optical

information recording medium, the spherical aberration is

largely generated at the time of recording or reproducing of

the information on the other optical information recording

medium. More specifically, in the case where the combination

of the objective lens and the optical information recording

medium of the transparent substrate thickness t1 is corrected
so that the spherical aberration is minimum for the incidence
of the infinite parallel light flux, when the optical
information recording medium having the transparent substrate
thickness of t2 (> t1) is recorded or reproduced, the
excessively corrected spherical aberration is generated in
the objective lens. Reversely, when the optical information
recording medium having the transparent substrate thickness
of t2'(< t1) is recorded or reproduced, the insufficently
corrected spherical aberration is generated in the objective
lens.

In contrast to that, for example, when the diffractive
surface is added to the objective lens, and the diffractive
lens having the wavelength dependency in which the light flux
of the different wavelength respectively forms the fine wave
front onto the optical information recording medium whose
transparent substrate thickness is different, is formed, the
spherical aberration when the transparent substrate thickness
is different cam be finely corrected. As described in the
optical pick-up apparatus of the 77th aspect, it is fine when
the diffraction light of the short wavelength forms the fine
wave front onto the optical information recording medium
having the small transparent substrate thickness, and the
diffraction light of the long wavelength forms the fine wave

front onto the optical information recording medium having
the large transparent substrate thickness.

More specifically, it is preferable that, when the
wavelength of the light source is minutely varied to the long
wavelength side, the diffractive surface has the spherical
aberration characteristic in which the spherical aberration
of the objective lens is insufficiently corrected. Further,
a divergent angle changing means for changing the divergent
angle of the light flux is provided and when the divergent
angle of the light flux incident to the objective lens is
changed to the divergent angle corresponding to the object
distance at which the spherical aberration becomes minimum,
the spherical aberration of the objective lens can be more
finely corrected. Particularly, when the light flux when the
spherical aberration is minimum to the optical information
recording medium having the transparent substrate thickness
of t2, is the divergent light, the working distance can be
easily secured. Because the role of the correction of the
spherical aberration deterioration when the transparent
substrate thickness is different can be allotted to the
divergent angle change means and the diffractive surface, the
movement amount of the movable portion of the divergent angle
change means can be small. Further, when the role of the
correction of the spherical aberration can be allotted to the

divergent angle change means and the diffractive surface, the

power of the diffractive surface can be reduced, and the

interval of the diffraction ring band is increased, and the

diffractive lens having the high diffraction efficiency can

be easily produced. In this connection, in the above

description, in the combination to the transparent substrate

thickness t1, the objective lens is corrected so that the

spherical aberration becomes minimum to the infinite light

flux, however, either objective lens may also be allowable in

which, to the divergent light flux from the finite distance

or the converging light flux toward the image side object,

the spherical aberration is corrected so as to be minimum,

and it is of course that, by the same manner as the above

description, the spherical aberration when the transparent

substrate thickness is different can be corrected.

(78) The optical pick-up apparatus described in (77) is

characterized in that it has the optical element provided

with the diffractive surface having the ring bans shaped

diffractive structure.

(79) The optical pick-up apparatus described in (78) is

characterized in that it has the wavelength characteristic in

which the diffractive surface of the optical element can

converge the first light flux emitted from the light source

of the oscillation wavelength $\lambda 1$ onto the information

recording plane of the first optical information recording medium of the transparent substrate thickness t1 in the condition not larger than the wave front aberration 0.07 λ1 rpm within a predetermined numerical aperture on the image side of the objective lens necessary for the recording or reproducing of the information, and can converge the second light flux emitted from the light source of the oscillation wavelength λ2 (λ1 < λ2) onto the information recording plane of the second optical information recording medium of the transparent substrate thickness t2 (t1 $\leqq$ t2) in the

condition not larger than the wave front aberration 0.07 λ2 rpm within a predetermined numerical aperture on the image side of the objective lens necessary for the recording or reproducing of the information. Specifically, the spherical aberration generated by the difference in the transparent substrate thickness is corrected by using the difference of the oscillation wavelengths of two light sources used for recording and/or reproducing the information for respective optical information recording media and the action of the diffractive structure provided on the diffractive surface.

(80) The optical apparatus described in (79) is characterized in that, when, to the information recording plane of the first optical information recording medium, a

predetermined numerical aperture on the image side of the

objective lens necessary for the recording or reproducing of

the information by the first light flux emitted from the

light source of the oscillation wavelength $\lambda 1$ is NA1, and to

the information recording plane of the second optical

information recording medium, a predetermined numerical

aperture on the image side of the objective lens necessary

for the recording or reproducing of the information by the

second light flux emitted from the light source of the

oscillation wavelength $\lambda 2$ is NA2 (NA1 > NA2), the diffractive

surface of the optical element light-converges the second

light flux emitted from the light source of the oscillation

wavelength $\lambda 2$ onto the information recording plane of the

second optical information recording medium within the NA1,

in the condition not smaller than the wave front aberration

0.07 $\lambda 2$ rms.

Particularly, as described in (80), it is preferable

that the spherical aberration is in the finely corrected

condition, to the combination of the oscillation wavelength

$\lambda 1$, transparent substrate thickness t1 and the image side

numerical aperture NA1, and the spherical aberration up to

the range of the image side numerical aperture NA2 necessary

for the combination of the oscillation wavelength $\lambda 2$,

transparent substrate thickness t2 and the image side

numerical aperture NA2, is corrected by the action of the

diffractive structure, and the spherical aberration of the

range from the image side numerical aperture NA2 to NA1 is

increased (it is largely generated as the flare component).

Thereby, when the second light flux of the oscillation

wavelength λ2 is incident to so that it passes through the

whole inside the diaphragm decided by the oscillation

wavelength λ1 and the image side numerical aperture NA1 of

the objective lens, the light flux more than the image side

numerical aperture NA2 does not contribute to the image

focusing of the spot, and because the spot diameter is not

too small on the information recording plane to the first

optical information recording medium of the transparent

substrate thickness t1, the generation of the false signal or

the detection of the unnecessary signal in the light

receiving means of the optical pick-up apparatus can be

prevented, and further, because it is not necessary that,

corresponding to the combination of the oscillation

wavelengths of the respective light sources and the

corresponding image side numerical apertures, a means for

switching the diaphragm is provided, a simple optical pick-up

apparatus can be obtained. Particularly, it is more

preferable that the second light flux emitted from the light

source of the oscillation wavelength $\lambda 2$ is converged onto the information recording plane of the second optical information recording medium, in the condition not smaller than the spherical aberration 0.2 $\lambda 2$ rms within the NA1.

(81) The optical pick-up apparatus described in one of (78) to (80) is characterized in that the objective lens is the optical element (the optical element provided with the diffractive surface having the ring band shaped diffractive structure). An optical pick-up apparatus described in the 82th aspect is characterized in that at least one surface of the objective lens is an aspherical single lens objective lens, and satisfies the following expression.

$$5.0 \leqq (f1/vd) \cdot fD1 \leqq 10.0 \qquad\qquad (9)$$

Where, f1: the focal length (mm) at the oscillation wavelength $\lambda 1$ of the whole objective lens in which the refracting power of the objective lens and the diffracting power by the diffractive structure of the objective lens are combined with together; vd: Abbe's number of d line of the objective lens; and fD1:   when the diffractive structure of the objective lens is expressed by the optical path difference function defined by $\Phi b = b_2 h^2 + b_4 h^4 + b_6 h^6 + \dots$ (herein, h is the height (mm) from the optical axis, and b_2, b_4, b_6, $\dots$ are the optical path difference function

coefficients of the second order, fourth order, sixth order,

…), the focal length (mm), which is defined by fD = 1/(-2 ·

b_2), at the oscillation wavelength $\lambda 1$ by only the diffractive

structure of the objective lens.

(83)   The optical pick-up apparatus described in (81) is

characterized in that at least one surface of the objective

lens is an aspherical single objective lens, and satisfies

the following expression.

$$-25.0 \leqq (b_2/\lambda 1) \leqq 0.0 \qquad\qquad (10)$$

Where, b_2:   the optical path difference function coefficient

of the second order, when the diffractive structure of the

objective lens is expressed by the optical path difference

function defined by $\Phi b = b_2 h^2 + b_4 h^4 + b_6 h^6 + …$ (herein, h is

the height (mm) from the optical axis, and b_2, b_4, b_6, … are

the optical path difference function coefficients of the

second order, fourth order, sixth order, …); and $\lambda 1$:   the

oscillation wavelength $\lambda 1$ (mm).   (82),(83)   An optical

pick-up apparatus relates to the optical pick-up apparatus by

which the axial chromatic aberration generated in the

objective lens and variation of the spherical aberration

generated on each optical surface of the converging optical

system can be finely corrected, to a plurality of optical

information recording media whose transparent substrate

thickness are different, and particularly to a case in which, in the optical pick-up apparatus using the same order diffraction light to the light fluxes of a plurality of light sources whose wavelengths are different from each other, the diffractive structure is provided on the objective lens, and by the action of the diffractive structure, the axial chromatic aberrations of the same order diffraction light are respectively corrected.

When the short wavelength light source (not larger than the oscillation wavelength about 500 nm) and the objective lens having the image side numerical aperture higher than the conventional image side numerical aperture (for example, about NA0.45 for the CD, and about NA 0.6 for the DVD) are used, in order to suppress the generation of the coma small, it is particularly effective that the transparent substrate thickness of the optical information recording medium is decreased to not larger than 0.2 mm, however, by satisfying the above expression (9), the axial chromatic aberration to both light fluxes of the short wavelength light source and the conventional long wavelength light source is not excessively corrected, or insufficiently corrected, and can be corrected with well balance, and when the diffractive structure having the wavelength characteristic by which respectively fine spots are formed on the respective

information recording planes to a plurality of optical

information media whose transparent substrate thickness is

different, is provided on the objective lens, also for the

conventional optical information recording medium whose

transparent substrate thickness (for example, 1.2 mm for the

CD, and 0.6 mm for the DVD) is large, by a single optical

pick-up apparatus (at least, the optical pick-up apparatus

which commonly uses the objective lens and its drive

mechanism), the recording or reproducing of the information

can be conducted. In the above expression (9), on more than

the lower limit of the left side, the axial chromatic

aberration is not excessively corrected for the light flux of

the long wavelength light source of 600 nm to 800 nm, and on

lower than the upper limit of the right side, the axial

chromatic aberration is not insufficiently corrected for the

light flux of the short wavelength light source not larger

than 500 nm, and it is preferable.

Further, by satisfying the above expression (10), the

burden of the aberration correction by the diffractive

structure provided on the objective lens can be lightened,

that is, by satisfying the above expression (10), because it

is possible that the role of the correction of the axial

chromatic aberration generated in the converging optical

system is not almost allotted to the diffractive structure

provided on the objective lens, the ring band interval of the diffractive structure can be large, the number of ring bands can be small, and the objective lens with the high diffraction efficiency can be obtained. Herein, when $b_2 = 0$, it corresponds to a case where the axial chromatic aberration is not corrected by the diffractive structure provided on the objective lens, and when $-25.0 \leqq (b_2/\lambda 1) < 0.0$, it corresponds to a case where the axial chromatic aberration is corrected for the light flux of the short wavelength light source (not larger than about 500 nm), to the degree in which the axial chromatic aberration is not excessively corrected for the light flux of the long wavelength light source (about 600 nm to 800 nm). In this manner, the axial chromatic aberration of insufficient correction can be corrected when the means for correcting the variation of the spherical aberration arranged between the objective lens an the light source is structured by the structure described in the 10th, 11th, 33th, 38th, 39th, 63th, and 65th aspects. Further, in the case where the axial chromatic aberration generated in the objective lens is corrected by the action of the diffractive structure, when Abbe's number of the material of the objective lens is νd, it is preferable that $\nu d > 55.0$ is satisfied, thereby, the second order spectrum can be suppressed to small.

(84)   The optical pick-up apparatus described in one of (78) to (83) is characterized in that the diffractive surface has a function to correct the axial chromatic aberration generated in the objective lens, for the minute variation of the oscillation wavelength of the light source.

(85)   In the optical pick-up apparatus described in one (78) to (84), because the diffractive surface has the wavelength characteristic in which the back focus of the objective lens becomes short when the oscillation wavelength of the light source is minutely varied to the long wavelength side, the axial chromatic aberration which is a problem when the short wavelength light source is used, can be finely corrected.

(86)   In the optical pick-up apparatus described in one (78) to (85) is characterized in that, when the oscillation wavelength of the light source is minutely varied to the long wavelength side, the diffractive surface has the spherical aberration characteristic in which the spherical aberration of the objective lens is varied to the direction of insufficient correction. Thereby, because the role of the spherical aberration correction can be allotted to the means for correcting the variation of the spherical aberration or the means for correcting the variation of the spherical aberration and the axial chromatic aberration, and the diffractive surface, when the means for correcting the

variation of the spherical aberration or the means for
correcting the variation of the spherical aberration and the
axial chromatic aberration, is structured by using the
optical element movable in the optical axis direction, the
stroke amount of the optical element is enough to be small.
Further, as described above, when the role of the spherical
aberration correction is allotted to the means for correcting
the variation of the spherical aberration or the means for
correcting the variation of the spherical aberration and the
axial chromatic aberration, and the diffractive surface, the
power of the diffractive surface can be suppressed, and the
because the interval of the diffraction ring band can be
large, the optical element with the high diffraction
efficiency can be easily produced.

(87),(88)   The optical pick-up apparatus described
respectively in one of (1) to (65) and (77) is characterized
in that the objective lens has at least the first part, the
second part and the third part, on at least one surface, by
which the light flux emitted from the light source is divided
into a plurality of light fluxes in the order from the
optical axis side to its outer periphery by the refractive
action, wherein the first part and the third part can
converge the light flux from the light source so that the
recording or the reproducing of the information can be

conducted for the information recording plane of the first

optical information recording medium of the transparent

substrate thickness t1, and the first part and the second

part can converge the light flux from the light source so

that the recording or the reproducing of the information can

be conducted for the information recording plane of the

second optical information recording medium of the

transparent substrate thickness t2 (t1 < t2).

(89)   The optical pick-up apparatus described in (77) is

characterized in that, on at least one surface of the

objective lens, a ring band shaped step portion to divide the

incident light flux into k (k $\geqq$ 4) ring band shaped light

fluxes (herein, in the order from the optical axis side to

the outside, the first, the second, ..., and the k-th light

flux, are defined), is formed, and when the recording and/or

reproducing of the information is conducted on the first

optical information recording medium, the spherical

aberration components of the wave front aberrations of the

first and the k-th light flux in the best image surface

position formed by the first and the k-th light flux are not

larger than 0.05 $\lambda 1$ rms (light source wavelength of $\lambda 1$), and

in the second to the (k - 1)-th light flux, at least 2 light

fluxes respectively form apparent best image surface

positions at different positions from the best image surface

positions formed by the first and the k-th light flux, and at

the best image surface positions formed by the first and the

k-th light flux, the wave front aberrations of the light rays

in respective light flux of the first to the k-th light flux

passing through the necessary numerical aperture to the first

optical information recording medium are almost $m_i\lambda 1$ (mi is

an integer, i = 1, 2, … , k).

According to the optical pick-up apparatus described in

(89), because the residual error is decreased in the

difference of the substrate thickness between the transparent

substrate thickness of the first optical information

recording medium (the first optical disk) and the transparent

substrate thickness of the second optical information

recording medium (the second optical disk), the recording

and/or reproducing of the information can be appropriately

conducted on a plurality of kinds of optical disks. For such

the objective lens, referring to Fig. 26, description will be

made later.

(90) The optical pick-up apparatus described in one of (77)

to (86), (88) or (89) is characterized in that the

transparent substrate thickness t1 of the first optical

information recording medium is not larger than 0.6 mm, the

transparent substrate thickness t2 of the second optical

information recording medium is not smaller than 0.6 mm, and

the oscillation wavelength $\lambda 2$ is within the range of not
smaller than 600 nm and not larger than 800 nm.

(91)   The optical pick-up apparatus described in one of (1)
to (90) is characterized in that, in the spherical aberration
of the objective lens, when the tertiary spherical aberration
component is SA1, and the sum of the fifth, seventh, and
ninth spherical aberration components is SA2, the following
expression is satisfied.

$\quad$ $|SA1/SA2| > 1.0$ $\qquad$ (11)

Where, SA1: the tertiary spherical aberration component when
the aberration function is developed into Zernike's
polynomial; and SA2:   root of the sum of squares of the
fifth spherical aberration component, the seventh spherical
aberration component, and the ninth spherical aberration
component when the aberration function is developed into
Zernike's polynomial.

$\quad$ The optical pick-up apparatus described in (91) relates
to a balance in the practical order spherical aberration
component of the spherical aberration generated in the
objective lens. Particularly, in the single lens objective
lens having the high image side aperture, because there is a
tendency in which an amount of the spherical aberration is
increased by a slight difference of the central thickness
(axial thickness), the allowable range of the central

thickness required for the objective lens becomes very
narrow, further, when the lens is produced by the molding, it
is also difficult to obtain a plurality of lenses in the
deviation of the central thickness not larger than several
μm, however, by satisfying the above expression (11), because
the tertiary spherical aberration component can be
comparatively easily corrected by the means for correcting
the variation of the spherical aberration or the means for
correcting the variation of the spherical aberration and the
axial chromatic aberration, the allowable range of the
central thickness (particularly, the error from the designed
value) can be expanded.

(92)   The optical pick-up apparatus described in one of (1)
to (91) is characterized in that a diaphragm to determine the
numerical aperture of the objective lens is positioned on the
side at which the optical information recording medium is
arranged, from the surface top of the surface on the most
light source side of the objective lens. Thereby, when the
divergent light is incident to the objective lens, because
the pass height of the ray of light on the surface on the
most light source side can be suppressed to small, it is
preferable for the size reduction of the objective lens or
the aberration correction of the objective lens.

(93)   In the optical pick-up apparatus described in one of
(1) to (92), because the objective lens is the single lens
objective lens having the aspherical surface on at least one
surface, the spherical aberration or the coma can be
effectively corrected, and the small sized and light weight
compact optical pick-up apparatus can be provided.
Particularly, when both surfaces are asperical, because the
spherical aberration and the coma can be effectively
corrected, it is more preferable.

(94)   In the optical pick-up apparatus described in one of
(1) to (93), because the light source has the oscillation
wavelength of at least not larger than 500 nm, the recording
of the high density information or reproducing of the high
density recording signal becomes possible. Further, the
axial chromatic aberration which is a problem when the short
wavelength light source with the oscillation wavelength not
larger than 500 nm is used, can be corrected particularly by
the structure described in 10th, 11th, 33th, 38th, 39th, 63th
or 65th aspect.

(95)   The optical pick-up apparatus described in one of (1)
to (94) is characterized in that the image side numerical
aperture NA of the objective lens is at least not smaller
than 0.65. When the image side numerical aperture of the
objective lens is not smaller than 0.65 (more preferably, not

smaller than 0.75), which is larger than the conventional

one, the greater increase of density and capacity of the

optical information recording medium can be attained. Giving

specific numerical values, the present invention will be

described below. Because the spot diameter converged onto

the optical information recording medium can be expressed by

$k\lambda/NA$ (k: proportional constant, λ: the oscillation

wavelength of the light source, NA: the image side numerical

aperture of the objective lens), in the high density optical

pick-up optical system using the blur purple semiconductor

laser of the oscillation wavelength 400 nm, and the objective

lens of the image side numerical aperture 0.85, as compared

to the low density optical pick-up optical system using the

red semiconductor laser of the oscillation wavelength 650 nm,

and the objective lens of the image side numerical aperture

0.65, the spot diameter is about 1/2. Herein, because the

recording density onto the optical information recording

medium is proportional to the square of the inverse number of

the ratio of the spot diameter, the recording density of the

high density optical pick-up optical system is about 4 times

of that of the low density optical pick-up optical system.

(96) The optical pick-up apparatus described in one of (1)

to (95) is characterized in that the objective lens

satisfies the following expression.

1.1 $\leqq$ d1/f $\leqq$ 3.0   (12)

Where, d1: axial lens thickness (mm) and

        f: focal length (mm) at the oscillation wavelength

of the light source, (in this connection, when the light

source has a plurality of light sources with different

oscillation wavelength, the focal length at the oscillation

wavelength whose wavelength is shortest, and when the

diffractive surface is provided on the objective lens, the

focal length of the whole in which the refracting power and

the diffracting power are combined).

The above expression (12) relates to a condition to

obtain the good image height characteristic. In the case

where the large image side numerical aperture larger than

0.65 is desired, when the value d1/f is not lower than the

lower limit, the good image height characteristic can be

secured, and the shift sensitivity can be decreased.

Further, because an angle formed between the contact surface

of the aspherical surface at the maximum position of the

effective diameter of the objective lens and the surface

perpendicular to the optical axis can be decreased, the

processing of the molding die when the lens is molded becomes

easy. On the one hand, when the value d1/f is not smaller

than the upper limit, because the central thickness (axial

thickness) is not too large, the working distance can be

secured large. Further, because the generation of the

astigmatism can be suppressed to small, the good image height

characteristic can be secured. According to the above, it is

more preferable that the value d1/f satisfied the following

expression.

$$1.2 \leqq d1/f \leqq 2.3 \qquad (12')$$

Further, it is particularly preferable to satisfy the

following expression.

$$1.4 \leqq d1/f \leqq 1.8 \qquad (12'')$$

(97) The optical pick-up apparatus described in one of (1)

to (96) is characterized in that the objective lens is formed

of the plastic material. When the objective lens is formed

of the plastic, the weight reduction can be attained, and the

burden onto the focusing mechanism can be decreased.

Further, the objective lens can be produced with a stable

accuracy and a large amount at a low cost. Further, when the

aspherical surface or the diffractive surface is provided on

the objective lens, these surfaces can be easily formed.

Particularly, it is preferable to produce them by the

injection molding (injection compression molding is

included).

(98) The optical pick-up apparatus described in one of (1)

to (97) is characterized in that the objective lens is formed

of the material whose saturation water absorption is not

larger than 0.5 %. Thereby, because the refractive index change of the objective lens by the humidity absorption becomes small, it is preferable.

(99) The optical pick-up apparatus described in one of (1) to (98) is characterized in that the objective lens is formed of the material whose internal permeability is not smaller than 85 % at the thickness 3mm for the light of the oscillation wavelength of the light source. Thereby, because the light source having the high light intensity is not necessary, the energy saving can be attained.

(100) The optical pick-up apparatus described in one of (1) to (99) is characterized in that it can be applied to the optical pick-up apparatus described in any one of the first to 99th aspects.

(101) The optical pick-up apparatus described in one of (1) to (99) is characterized in that it is the objective lens used for the optical pick-up apparatus described in any one of the first to 99th aspects.

(102) An objective lens is characterized in that, in the objective lens for use in the optical pick-up apparatus by which recording and/or reproducing of the information can be conducted for at least 2 kinds of optical information recording media, and which has the light source of the oscillation wavelength $\lambda 1$, the light source of the

oscillation wavelength λ2 which is different from the

oscillation wavelength λ1 (λ1 < λ2), the converging optical

system including the objective lens for light-converging the

first light flux emitted from the light source of the

oscillation wavelength λ1 onto the information recording

plane of the first optical information recording medium

through the transparent substrate of the transparent

substrate thickness t1, and for light-converging the second

light flux emitted from the light source of the oscillation

wavelength λ2 onto the information recording plane of the

first optical information recording medium through the

transparent substrate of the transparent substrate thickness

t2 (t1 ≦ t2), and the light detector for light-receiving

the reflected light from the first and second optical

information recording medium, the following expression is

satisfied.

$$1.1 \leqq d1/f \leqq 3.0 \qquad (13)$$

Where, d1: axial lens thickness (mm) and

f: focal length (mm) at the oscillation wavelength

λ1, (in this connection, when the diffractive surface is

provided on the objective lens, the focal length of the whole

in which the refracting power and the diffracting power are

combined).

(103) The objective lens described in (102) is characterized in that the image side numerical aperture NA is not smaller than 0.75.

(104) The objective lens described in (102) or (103) is characterized in that it is provided with the diffractive surface having the ring band shaped diffractive structure.

(105) The objective lens described in (104) is characterized in that the diffractive surface has the wavelength characteristic which can converge the first light flux emitted from the light source of the oscillation wavelength $\lambda1$ onto the information recording plane of the first optical information recording medium in the condition not larger than the wave front aberration 0.07 $\lambda1$ rpm within a predetermined numerical aperture on the image side of the objective lens necessary for the recording or reproducing of the information, and can converge the second light flux emitted from the light source of the oscillation wavelength $\lambda2$ onto the information recording plane of the second optical information recording medium in the condition not larger than the wave front aberration 0.07 $\lambda2$ rpm within a predetermined numerical aperture on the image side of the objective lens necessary for the recording or reproducing of the information.

(106) The objective lens described in (104) or (105) is characterized in that when, to the information recording plane of the first optical information recording medium, a predetermined numerical aperture on the image side of the objective lens necessary for the recording or reproducing of the information by the first light flux emitted from the light source of the oscillation wavelength $\lambda 1$ is NA1, and to the information recording plane of the second optical information recording medium, a predetermined numerical aperture on the image side of the objective lens necessary for the recording or reproducing of the information by the second light flux emitted from the light source of the oscillation wavelength $\lambda 2$ is NA2 (NA1 > NA2), the diffractive surface light-converges the second light flux emitted from the light source of the oscillation wavelength $\lambda 2$ onto the information recording plane of the second optical information recording medium within the NA1, in the condition not smaller than the wave front aberration 0.07 $\lambda 2$ rms.

(107) The objective lens described in one of (104) to (106) is characterized in that the diffractive surface has a function to suppress the axial chromatic aberration to the minute variation of the oscillation wavelength of the light source.

(108) The objective lens described in one of (104) to (107) is characterized in that the diffractive surface has the wavelength characteristic to shorten the back focus of the objective lens when the oscillation wavelength of the light source is minutely varied onto the long wavelength side.

(109) The objective lens described in one of (104) to (108) is characterized in that the diffractive surface has the spherical aberration characteristic which varies to the direction in which the spherical aberration of the objective lens becomes an insufficient correction condition when the oscillation wavelength of the light source is minutely varied onto the long wavelength side.

(110) The objective lens described in one of (102) to (109) is characterized in that it is an single lens whose at least one surface is an aspherical surface, and satisfies the following expression.

$$0.5 \leqq (f1/vd) \cdot fD1 \leqq 10.0 \qquad (14)$$

Where, f1: the focal length (mm) of the objective lens in which the refracting power of the objective lens and the diffracting power by the diffractive structure of the objective lens are combined with together, at the oscillation wavelength λ1; vd: Abbe's number of d line of the lens material; and fD1: when the diffractive structure is expressed by the optical path difference function defined by

$\Phi b = b_2 h^2 + b_4 h^4 + b_6 h^6 + \dots$ (herein, h is the height (mm) from the optical axis, and b_2, b_4, b_6, … are the optical path difference function coefficients of the second order, fourth order, sixth order, …), the focal length (mm) at the oscillation wavelength $\lambda 1$ by only the diffractive structure, which is defined by $fD = 1/(-2 \cdot b_2)$.

By satisfying the above expression (14), the axial chromatic aberration to both light fluxes of the short wavelength light source and the conventional long wavelength light source is not excessively corrected, or insufficiently corrected, and can be corrected with well balance. In the above expression (14), in more than the lower limit of the left side, the axial chromatic aberration is not excessively corrected for the light flux of the long wavelength light source of 600 nm to 800 nm, and in lower than the upper limit of the right side, the axial chromatic aberration is not insufficiently corrected for the light flux of the short wavelength light source not larger than 500 nm, and it is preferable. When the diffractive structure having the wavelength characteristic by which respectively fine spots are formed on the respective information recording planes to a plurality of optical information recording media whose transparent substrate thickness is different, is provided on the objective lens, also for the conventional optical

information recording medium whose transparent substrate

thickness (for example, 1.2 mm for the CD, and 0.6 mm for the

DVD) is large, and also for the optical information recording

medium whose transparent substrate thickness is small (for

example, the transparent substrate thickness is not larger

than 0.2 mm), for which the short wavelength light source and

the high image side numerical aperture are necessary, an

objective lens which can be commonly used for the recording

or reproducing of the information, can be obtained.

(111) The objective lens described in one of (102) to (109)

is characterized in that it is an single lens whose at least

one surface is an aspherical surface, and satisfies the

following expression.

$$-25.0 \leqq (b_2/\lambda1) \leqq 0.0 \qquad (15)$$

Where, b_2:   the optical path difference function coefficient

of the second order, when the diffractive structure is

expressed by the optical path difference function defined by

$\Phi b = b_2h^2 + b_4h^4 + b_6h^6 + \ldots$ (herein, h is the height (mm) from

the optical axis, and b_2, b_4, b_6, … are the optical path

difference function coefficients of the second order, fourth

order, sixth order, …); and $\lambda1$:

the oscillation wavelength $\lambda1$ (mm).

Further, by satisfying the above expression (15), the
burden of the aberration correction by the diffractive
structure provided on the objective lens can be lightened,
that is, by satisfying the above expression (15), because it
is possible that the role of the correction of the axial
chromatic aberration generated in the converging optical
system is not almost allotted to the diffractive structure
provided on the objective lens, the ring band interval of the
diffractive structure can be large, the number of ring bands
can be small, and the objective lens with the high
diffraction efficiency can be obtained. Herein, when $b_2 = 0$,
it corresponds to a case where the axial chromatic aberration
is not corrected by the diffractive structure provided on
the objective lens, and when $-25.0 \leqq (b_2/\lambda 1) < 0.0$, it
corresponds to a case where the axial chromatic aberration is
corrected for the light flux of the short wavelength light
source (not larger than about 500 nm), to the degree in which
the axial chromatic aberration is not excessively corrected
for the light flux of the long wavelength light source (about
600 nm to 800 nm). In this manner, the axial chromatic
aberration of insufficient correction can be corrected when
the means for correcting the variation of the spherical
aberration arranged between the objective lens an the light
source is structured by the structure described in (10),

(11), (33), (38), (39), (63), (65). Further, in the case where the axial chromatic aberration generated in the objective lens is corrected by the action of the diffractive structure, when Abbe's number of the material of the objective lens is νd, it is preferable that νd > 55.0 is satisfied, thereby, the second order spectrum can be suppressed to small.

(112) The objective lens described in one of (102) to (111) is characterized in that, in the spherical aberration, when the tertiary spherical aberration component is SA1, and the sum of the fifth, seventh, and ninth spherical aberration components is SA2, the following expression is satisfied.

$$|SA1/SA2| > 1.0 \qquad (16)$$

Where, SA1: the tertiary spherical aberration component when the aberration function is developed into Zernike's polynomial; and SA2:   root of the sum of squares of the fifth spherical aberration component, the seventh spherical aberration component, and the ninth spherical aberration component when the aberration function is developed into Zernike's polynomial.

This relates to a balance in the practical order spherical aberration component of the spherical aberration generated in the objective lens. Particularly, in the single lens objective lens having the high image side aperture,

because there is a tendency in which an amount of the
spherical aberration is increased by a slight difference of
the central thickness (axial thickness), the allowable range
of the central thickness required for the objective lens
becomes very narrow, further, when the lens is produced by
the molding, it is also difficult to obtain a plurality of
lenses in the deviation of the central thickness not larger
than several μm, however, by satisfying the above expression
(11), the balance in the spherical aberration components of
the practical order generated in the objective lens can be
made fine, and the allowable range of the central thickness
(particularly, the error from the designed value) required
for the objective lens can be expanded.

(113) The objective lens described in (102) or (103) is
characterized in that it has at least the first part, the
second part and the third part, on at least one surface, by
which the light flux emitted from the light source is divided
into a plurality of light fluxes in the order from the
optical axis side to its outer periphery by the refractive
action, wherein the first part and the third part can
converge the light flux from the light source of the
oscillation wavelength $\lambda 1$ so that the recording or the
reproducing of the information can be conducted for the
information recording plane of the first optical information

recording medium, and the first part and the second part can converge the light flux from the light source of the oscillation wavelength λ2 so that the recording or the reproducing of the information can be conducted for the information recording plane of the second optical information recording medium.

(114) The objective lens described in (102) or (103) is characterized in that, on at least one surface of the objective lens, a ring band shaped step portion to divide the incident light flux into k (k ≧ 4) ring band shaped light fluxes (herein, in the order from the optical axis side to the outside, the first, the second, ..., and the k-th light flux, are defined), is formed, and when the recording and/or reproducing of the information is conducted on the first optical information recording medium, the spherical aberration components of the wave front aberrations of the first and the k-th light flux in the best image surface position formed by the first and the k-th light flux are not larger than 0.05 λ1 rms (light source wavelength of λ1), and in the second to the (k − 1)-th light flux, at least 2 light fluxes respectively form apparent best image surface positions at different positions from the best image surface positions formed by the first and the k-th light flux, and at

the best image surface positions formed by the first and the

k-th light flux, the wave front aberrations of the light rays

in respective light flux of the first to the k-th light flux

passing through the necessary numerical aperture to the first

optical information recording medium are almost $mi\lambda1$ (mi is

an integer, i = 1, 2, … , k).

(115) The objective lens described in one of (102) to (114)

is characterized in that it is formed of the plastic

material.

(116) The objective lens described in one of (102) to (115)

is characterized in that it is formed of the material whose

saturation water absorption is not larger than 0.5 %.

(117) The objective lens described in one of (102) to (116)

is characterized in that it is formed of the material whose

internal permeability is not smaller than 85 % at the

thickness 3 mm, to the oscillation wavelength of the light

source.

(118) The objective lens described in one of (102) to (117)

is characterized in that it is a single lens at least one

surface of which is aspherical surface.

(119) The objective lens described in one of (102) to (118)

is characterized in that it can be applied for the optical

pick-up apparatus described in any one of (1) to (99).

(120) A beam expander is characterized in that it includes at
least one positive lens and at least one negative lens, and
at least one of them is a movable element which can transfer
along the optical axis direction, and respective Abbe's
numbers of all positive lenses including the positive lens
are not larger than 70.0 or respective Abbe's numbers of all
negative lenses including the negative lens are not smaller
than 40.0, and it has the diffractive surface having the ring
band shaped diffractive structure on at least one surface.

When Abbe's number of the positive lens constituting
the beam expander is not smaller than 70.0 or Abbe's number
of the negative lens is not smaller than 40.0, the axial
chromatic aberration generated in the other optical element
(particularly, preferably, the objective lens when being
applied for the optical pick-up apparatus) is apt to be in
insufficient correction condition, however, when the
diffractive surface is provided, the axial chromatic
aberration can be finely corrected. Particularly, when the
diffractive surface having the wavelength characteristic in
which the back focus becomes short when the oscillation
wavelength of the incident light source is minutely varied to
the long wavelength side, is provided on at least one
surface, the axial chromatic aberration of the objective lens
can be finely corrected. Further, when Abbe's number of the

positive lens is not larger than 70.0, the strength is

excellent, the production is easy, and also for the anti-

environment, it is good. On the one hand, when Abbe's number

of the negative lens is not smaller than 40.0, the

penetrability for the light of short wavelength is excellent.

For both the positive lens and the negative lens, it is

preferable that Abbe's numbers are not smaller than 40.0 and

not larger than 70.0.

(121) The beam expander described in (120) is characterized

in that, when the paraxial power in the oscillation

wavelength of the light source which outputs the light flux

to be incident, is P1, the paraxial power in the wavelength

which is 10 nm shorter than the oscillation wavelength is P2,

and the paraxial power in the wavelength which is 10 nm

longer than the oscillation wavelength is P3, the following

expression is satisfied.

$$P2 < P1 < P3 \hspace{3cm} (17)$$

According to this, the role for correcting the axial

chromatic aberration generated in the optical element such as

the objective lens or the coupling lens can be allotted to

the beam expander. That is, in the beam expander itself, the

axial chromatic aberration is excessively corrected by the

diffractive structure, and by generating the axial chromatic

aberration whose polarity is reverse to the axial chromatic

aberration generated in the optical element such as the objective lens or coupling lens, the axial chromatic aberration generated in the optical element such as the objective lens or coupling lens can be corrected.

(122) The beam expander described in (120) or (121) is characterized in that the diffractive surface has the function to suppress the axial chromatic aberration generated in the condenser lens arranged on the light emission side with respect to the minute variation of the oscillation wavelength of the light source which outputs the light flux to be incident.

(123) The beam expander described in one of (120) to (122) is characterized in that, when the oscillation wavelength of the light source which outputs the light flux to be incident, is minutely varied to the long wavelength side, the diffractive surface has the wavelength characteristic so that the back focus of the condenser lens arranged on the light emission side becomes short. According to this, the axial chromatic aberration of the optical element such as the objective lens can be finely corrected.

(124) The beam expander described in one of (120) to (123) is characterized in that, when the oscillation wavelength of the light source which outputs the light flux to be incident, is minutely varied to the long wavelength side, the diffractive

surface has the spherical aberration characteristic in which the spherical aberration of the condenser lens arranged on the light emission side is changed to the direction of the insufficient correction. Thereby, the spherical aberration generated when the oscillation wavelength of the light source which outputs the light flux to be incident, is minutely varied to the long wavelength side, can be finely corrected.

(125) The beam expander described in one of (120) to (124) is characterized in that the movable element is formed of the material whose specific density is not larger than 2.0. According to this, the burden of the movable element onto the transfer apparatus can be lightened.

(126) The beam expander described in one of (120) to (125) is characterized in that the movable element is formed of the plastic material. According to this, the burden onto the transfer apparatus can be lightened, and the high speed transfer of the movable element in the optical axis direction becomes possible. Further, when the structural element on which the diffractive surface or aspherical surface is provided, is formed of the plastic material, these can be easily added.

(127) The beam expander described in one of (120) to (126) is characterized in that it has the aspherical surface on at least one surface of the movable element.

(128) The beam expander described in one of (120) to (127) is characterized in that the movable element is formed of the material whose saturation water absorption is not larger than 0.5 %.

(129) The beam expander described in one of (120) to (128) is characterized in that the movable element is formed of the material whose internal permeability is not smaller than 85 % at the thickness 3 mm, to the light of the oscillation wavelength of the light source to be incident.

(130) The beam expander described in one of (120) to (124) is characterized in that it is formed of the plastic material.

(131) The beam expander described in one of (120) to (124) or (130) is characterized in that it has an aspherical surface on at least one surface.

(132) The beam expander described in one of (120) to (124), (130) or (131) is characterized in that it is formed of the material whose saturation water absorption is not larger than 0.5 %.

(133) The beam expander described in one of (120) to (124) and (130) to (132) is characterized in that it is formed of the material whose internal permeability is not smaller than 85 % at the thickness 3 mm, to the light of the oscillation wavelength of the light source to be incident.

(134) The beam expander described in one of (120) to (133) is characterized in that it can be applied for the optical pick-up apparatus described in any one of (8) to (33) and (36) to (63).

(135) A converging optical system is one on an optical pick-up apparatus for recording and/or reproduction for an optical information recording medium, the converging optical system including a coupling lens which changes a divergence angle of divergent light emitted from a light source and including an objective lens that converges a light flux that has passed the coupling lens on the image recording surface through a transparent substrate of an optical information recording medium, and a ring-shaped band diffractive structure is formed on at least one optical surface of an optical element constituting the converging optical system, the coupling lens is of a 2-group structure, and deviation of spherical aberration caused on each optical surface of the converging optical system is corrected by moving at least one lens group constituting the coupling lens in the optical axis direction, which is a special feature.

The converging optical system of (135) relates to the preferable structure of a converging optical system used for an optical pick-up apparatus for conducting recording and/or reproduction for an advanced optical information recording

medium that is higher in terms of density and larger in terms
of capacity than DVD. BY providing, on at least one optical
surface of an optical element constituting the converging
optical system, the diffractive structure having the
wavelength characteristic wherein a back focus of an
objective lens is shortened when a wavelength of a light
source fluctuates slightly toward the long wavelength side,
it is possible to correct effectively axial chromatic
aberration that is caused on an objective lens and is
problematic when a short wavelength light source such as a
violet semiconductor laser is used. Though the diffractive
structure stated above may also be provided on an optical
element other than a coupling lens that is arranged
separately to be closer to a light source than an objective
lens, it is preferable to provide it on an objective lens
and/or coupling lens because the number of structural
elements of a converging optical system is less and an
optical pick-up apparatus can be made small in size
accordingly. When providing the diffractive structure on an
optical surface of a coupling lens, the minimum ring-shaped
band distance of the diffractive structure to be provided on
one optical surface can be made large, because it is possible
to make two or more optical surfaces to share in power of

diffraction, and thus, diffraction efficiency can be
enhanced.

Further, when at least one of two lens groups
constituting a coupling lens is made to be capable of moving
in the direction of an optical axis, it is possible to
correct deviation of spherical aberration caused on each
optical surface in the converging optical system, especially
on an optical surface of an objective lens. Since it is
possible to correct, on a real time basis, the spherical
aberration caused greatly on an objective lens by minute
deviation of emission wavelength of a light source, changes
in temperature and humidity and/or errors of a thickness of a
transparent substrate of an optical information recording
medium which cause a problem when an objective lens having a
high numerical aperture that is necessary for recording
information at higher density than a conventional optical
information recording medium and/or for reproducing
information recorded at high density is used,
an appropriate spot can always be formed on an information
recording plane of an optical information recording medium.

By moving the movable lens group of the coupling lens
in the direction of an optical axis, it is possible to
correct spherical aberration caused by an error of forming an
optical element that constitutes a converging optical system.

When manufacturing an optical element through a forming

method employing a metal mold in general, there are generated

errors for machining a metal mold and for forming an optical

element. Examples of the error include an error in a

thickness of the central portion and an error in a form of an

optical surface. If a component of aberration caused by

these errors is third order spherical aberration, it is

possible to correct it by moving the movable lens group of

the coupling lens in the direction of an optical axis in the

converging optical system of the invention. Therefore, a

tolerance in manufacture of an optical element that forms a

converging optical system can be made large, and thereby,

productivity can be enhanced.

(136) In the converging optical system described in (135),

the light source stated above emits light having a wavelength

of not more than 600 nm, and axial chromatic aberration

generated by a refraction action of each refracting interface

in the converging optical system and axial chromatic

aberration generated by the diffractive structure offset each

other.

Though recording at density higher than that in a

conventional optical information recording medium and/or

reproduction of information recorded at higher density is

possible for an optical information recording medium, by

employing a light source generating light having an

oscillation wavelength of not more than 600 nm, as shown in

(136), the axial chromatic aberration caused on the

converging optical system, especially on an objective lens as

stated above is a problem. When axial chromatic aberration

whose polarity is opposite to that of axial chromatic

aberration generated on each refracting interface of the

converging optical system is generated on the diffractive

structure mentioned above, the wavefront in the case of

forming a spot on an information recording plane of an

optical information recording medium through a converging

optical system is in the state wherein axial chromatic

aberrations are canceled, and thereby, it is possible to

create a system wherein axial chromatic aberration is

corrected satisfactorily within a range of wavelength

deviation of a light source as an overall converging optical

system.

Incidentally, it is preferable that a converging

optical system of the invention is made of optical materials

whose inner transmission factor in thickness of 3 mm is 85%

or more for light having an oscillation wavelength of a light

source. When using a light source with a short wavelength

having an oscillation wavelength of not more than 600 nm,

especially of about 400 nm, a fall of a transmission factor

caused by absorption of light by optical materials is a
problem. However, by making the converging optical system
with materials having the aforesaid inner transmission
factor, it is possible to form a spot having high quantity of
light without increasing output of a light source in the
course of recording, and to improve an S/N ratio of a reading
signal in reproduction.

It is further preferable that a converging optical
system of the invention is made of optical materials whose
saturated coefficient of water absorption is not more than
0.5%. If this condition is observed, a refractive index
distribution caused by a difference in coefficient of water
absorption is hardly generated in an optical element in the
course for each optical element constituting a converging
optical system to absorb moisture in the air, and thereby,
aberration generated and a fall of diffraction efficiency
caused by phase change can be repressed. When the numerical
aperture of an objective lens is great, in particular,
generation of aberration and a fall of diffraction efficiency
tend to take place more. However, they can be suppressed to
a lower level sufficiently by doing in the aforesaid manner.
(137) In the converging optical system described in (136),
axial chromatic aberration of a composition system composed
of the coupling lens, an optical element having thereon the

diffractive structure and the objective lens satisfies the following expression;

$$|\triangle fB \cdot NA^2| \leq 0.25 \ \mu m \qquad\qquad (17)$$

wherein, NA represents the numerical aperture of the prescribed objective lens on the subject side necessary for recording and/or reproducing for an optical information recording medium, and $\triangle fB$ represents a change (μm) of a focus position of the composition system corresponding to the change of + 1 nm in wavelength of the light source.

When axial chromatic aberration generated on each refracting interface of a converging optical system is corrected by utilizing an action of the diffractive structure, it is preferable that axial chromatic aberration of the converging optical system, namely, axial chromatic aberration of a composition system composed of a coupling lens, an optical element having thereon a diffractive structure and an objective lens satisfies the conditional expression (17) of (137).

(138) In the converging optical system described in one of (135) to (137), the numerical aperture of the prescribed objective lens on the subject side necessary for recording and/or reproducing for an optical information recording medium is 0.65 or more, and a thickness of a transparent

substrate of the optical information recording medium is not
more than 0.6 mm.

Since it is possible to reduce a size of a spot
converged on an information recording plane by enhancing the
numerical aperture of the prescribed objective lens on the
subject side necessary for recording and/or reproduction for
an optical information recording medium to 0.65 or more (0.45
for a conventional optical information recording medium, such
as CD, for example, and 0.60 for DVD), as shown in (138),
recording at density higher than that in a conventional
optical information recording medium and/or reproduction of
information recorded at higher density is possible for an
optical information recording medium. However, the
enhancement of the numerical aperture of an objective lens
causes a problem that occurrence of coma caused by an
inclination of an optical information recording medium from
the surface perpendicular to the optical axis or by a warp
thereof is more remarkable. By making a thickness of a
transparent substrate of an optical information recording
medium to be smaller, occurrence of coma can be repressed.
When the numerical aperture of the objective lens is enhanced
to 0.65 or more, it is preferable to make a thickness (t) of
a transparent substrate of an optical information recording
medium to be 0.6 or less ((1.2 mm for a conventional optical

information recording medium, for example, CD, and 0.6 mm for

DVD). To be concrete, in the case of $0.65 \leq NA \leq 0.70$, $0.3 \leq$

$t \leq 0.6$ is preferable, while,

in the case of $0.70 \leq NA \leq 0.85$, $0.0 \leq t \leq 0.3$ is preferable.

(139) In the converging optical system described in one of

(135) to (138), a lens group capable of moving in the

direction of an optical axis among those constituting the

coupling lens has positive refracting power, and satisfies

the following expression;

$$4 \leq f_{CP}/f_{OBJ} \leq 17 \qquad\qquad (18)$$

wherein f_{CP} represents focal length (mm) of a lens group that

can move in the direction of an optical axis and has positive

refracting power, and f_{OBJ} represents a focal length of the

objective lens.

When a lens group having positive refracting power

among those constituting a coupling lens is made to be

capable of moving in the direction of an optical axis as

shown in (139), it is preferable that expression (18) is

satisfied. When the upper limit in expression (18) is not

exceeded, an amount of movement for correcting deviation of

spherical aberration caused on a converging optical system

can be small, which makes the total converging optical system

to be compact. When the lower limit in expression (2) is not

exceeded, it is possible to repress refracting power of the movable lens group to be small, and thereby to repress occurrence of aberration on the movable lens group. When two lens groups constituting a coupling lens are made to have positive refracting power, well-balanced distribution of refracting power to two lens groups can be carried out by satisfying expression (18), and each lens group can be made to have a form which is easy for manufacture.

(140) In the converging optical system described in one of (135) to (138), a lens group capable of moving in the direction of an optical axis among those constituting the coupling lens has negative refracting power, and satisfies the following expression;

$$-20 \leq f_{CN}/f_{OBJ} \leq -3 \qquad\qquad (19)$$

wherein f_{CN} represents focal length (mm) of a lens group that can move in the direction of an optical axis and has negative refracting power, and f_{OBJ} represents a focal length of the objective lens.

When a lens group having negative refracting power among those constituting a coupling lens is made to be capable of moving in the direction of an optical axis as shown in (140), it is preferable that expression (19) is satisfied. When the lower limit in expression (19) is not exceeded, an amount of movement for correcting deviation of

spherical aberration caused on a converging optical system
can be small, which makes the total converging optical system
to be compact. When the upper limit in expression (19) is
not exceeded, it is possible to repress refracting power of
the movable lens group to be small, and thereby to repress
occurrence of aberration on the movable lens group. It is
further possible to repress refracting power of the lens
group having positive refracting power among two lens groups
constituting a coupling lens to be small, and thereby, it is
possible to repress occurrence of aberration on the lens
group having positive refracting power, which makes
manufacture to be easy.

(141) In the converging optical system described in one of
(135) to (140), the objective lens is of a construction of 1-
group and 1-element, and at least one surface is aspherical.

By making an objective lens to be of a construction of
1-group and 1-element in which at least one surface is
aspherical as shown in (141), it is possible to obtain an
objective lens suitable for optical pick-up wherein spherical
aberration and coma are corrected satisfactorily in the
simple construction of 1-group and 1-element, and recording
at density higher than that in a conventional optical
information recording medium and/or reproduction of
information recorded at higher density is possible for an

optical information recording medium. Further, it is more
preferable that both surfaces are aspherical, and thereby,
aberration can be corrected more accurately. Further, by
making an objective lens to be of a construction of 1-group
and 1-element, it is possible to secure a working distance to
be long even when the numerical aperture is great, and
thereby to prevent the contact between an objective lens and
an optical information recording medium caused by a warp or
inclination of the optical information recording medium.

(142) In the converging optical system described in one of
(135) to (140),the objective lens is of a construction of 2-
group and 2-element, and at least two surfaces among the
first surface up to the third surface are aspherical.

By making an objective lens to be of a construction of
2-group and 2-element as shown in (142), it is possible to
distribute refracting power for a ray of light to four
surfaces, thus, refracting power per one surface can be small
even when the numerical aperture is made to be great. As a
result, a tolerance for eccentricity between lens surfaces
can be large in making a metal mold and in forming a lens,
resulting in a lens that is easy to be manufactured. By
distributing refracting power for a ray of light to four
surfaces, there is produced a room in correcting operations
for aspherical surfaces provided on at least two surfaces

among the first surface up to the third surface, which makes

it possible to correct spherical aberration and coma

accurately. In this case, it is preferable that at least two

surfaces including the first surface and the third surface

are made to be aspherical. It is further preferable that the

second surface is also made to be aspherical, because

aberration caused by deviation of an optical axis between the

first lens and the second lens can be controlled to be small.

(143) In the converging optical system described in one of

(135) to (142), an optical element having thereon a

diffractive structure is made of plastic material, and

therefore, the diffractive structure can easily be provided,

which makes it possible to manufacture at low cost on a mass

production basis through an injection molding method

employing a metal mold.

(144) In the converging optical system described in one of

(135) to (143), it is preferable that a lens group movable in

the direction of an optical axis among lens groups

constituting the coupling lens is made of material having

specific gravity of 2.0 or less, because inertia force in the

course of movement can be kept small and quick movement is

possible accordingly. Further, electric power for driving an

actuator representing a driving device for moving the movable

lens group can be small, and a small-sized actuator can be used.

(145)   In the converging optical system described in one of (134) to (144), it is preferable that a quantity of light of n-th order diffraction light (n represents integers other than 0 and ±1) is greater than that of diffraction light in any other order, and the converging optical system stated above can converge, on an information recording plane of the optical information recording medium, n-th order diffraction light generated on the diffractive structure in the course of information recording and/or reproduction for the optical information recording medium, because a ring-shaped band distance can be made large when the diffractive structure is formed by a plurality of zones, which makes manufacture to be easy.

(146)   In the converging optical system described in one of (135) to (145), it is possible to form an excellent spot on an information recording plane of an optical information recording medium and thereby no selection of a light source is needed, which is preferable, if deviation of spherical aberration caused on each optical surface of a converging optical system by deviation of oscillation wavelength of the light source is corrected by moving at least one lens group

constituting the coupling lens in the direction of an optical axis.

(147) In the converging optical system described in one of (135) to (146), even a plastic lens that is subject to a fall of image forming efficiency caused by temperature change and humidity change can be used as an objective lens with a high numerical aperture and extensive cost reduction can be attained for an optical pick-up apparatus, if the objective lens includes a lens formed with at least one plastic material sheet, and deviation of spherical aberration caused on each optical surface of a converging optical system by changes of temperature and humidity is corrected by moving at least one lens group constituting the coupling lens in the direction of an optical axis.

(148) In the converging optical system described in one of (135) to (146), it is possible to make a tolerance for manufacture for an optical information recording medium to be great, and thereby to enhance productivity, if deviation of spherical aberration caused by variation of a thickness of a transparent substrate of the information recording medium is corrected by moving at least one lens group constituting the coupling lens in the direction of an optical axis.

(149) In the converging optical system described in one of (135) to (146), deviation of spherical aberration caused on

each optical surface of a converging optical system by combination of at least two of deviation of oscillation wavelength of the light source, changes of temperature and humidity, and variation of a thickness of a transparent substrate of the information recording medium, is corrected by moving at least one lens group constituting the coupling lens in the direction of an optical axis.

In the converging optical system of the invention, as indicated in (147), deviation of spherical aberration caused by a combination of changes of temperature and humidity, or an error of a thickness of a transparent substrate of an optical information recording medium, or dispersion of oscillation wavelength of a light source from the standard wavelength, can be corrected, and therefore, it is possible to obtain a converging optical system whose light-converging characteristics are constantly excellent.

(150) In the converging optical system described in one of (135) to (149), the optical information recording medium has structure wherein a plurality of transparent substrates and a plurality of information recording layers are laminated alternately in this order from the surface of the optical information recording medium, the objective lens is moved in the direction of an optical axis for focusing for information recording and/or reproduction for each information recording

plane, and deviation of spherical aberration caused by a difference of a thickness of the transparent substrate on each information recording layer is corrected by moving at least one lens group constituting the coupling lens in the direction of an optical axis.

The converging optical system of (150) relates to one for an optical pick-up apparatus capable of recording and/or reproducing information for an optical information recording medium having structure wherein a plurality of transparent substrates and a plurality of information recording layers are laminated alternately in this order from the surface of the optical information recording medium. In this converging optical system, it is possible to correct spherical aberration caused by a difference in thickness for transparent substrates existing in the surface up to the information recording layer by moving the movable optical element of the coupling lens in the direction of an optical axis, and it is possible to focus on the aimed information recording layer by moving the objective lens in the direction of an optical axis, thus, it is possible to form an excellent wavefront on each information recording plane. Accordingly, information in doubled volume or more can be recorded on the surface on one side of the optical information recording medium and/or reproduced.

(151) An optical pick-up apparatus is one having therein a
converging optical system having a light source, a coupling
lens of a 2-group structure changing a divergence angle of
divergent light emitted from the light source and an
objective lens that converges a light flux passing through
the coupling lens on an information recording plane through a
transparent substrate of an optical information recording
medium, a detector that detects light reflected on the
information recording plane, the first driving device that
moves the objective lens in the direction of an optical axis
and in the direction perpendicular to an optical axis for
converging a light flux on the information recording plane,
and the second driving device that moves at least one optical
element of the coupling lens in the direction of an optical
axis, and conducts information recording and/or reproduction
for an information recording plane of the optical information
recording medium, wherein a ring-shaped band refractive
structure is formed on at least one optical surface of an
optical element constituting the converging optical system,
and the second driving device moves at least one lens group
constituting the coupling lens in the direction of an optical
axis to correct deviation of spherical aberration caused on
each optical surface of the converging optical system.

The optical pick-up apparatus of (151) relates to one for conducting recording and/or reproduction for an advanced optical information recording medium that is higher in terms of density and larger in terms of capacity than DVD. BY providing, on at least one optical surface of an optical element constituting the converging optical system of the optical pick-up apparatus, the diffractive structure having the wavelength characteristic wherein a back focus of an objective lens is shortened when a wavelength of a light source fluctuates slightly toward the long wavelength side, it is possible to correct effectively axial chromatic aberration that is caused on an objective lens and is problematic when a short wavelength light source such as a violet semiconductor laser is used. It is further possible to correct satisfactorily deviation of spherical aberration caused on each optical surface of the converging optical system by making at least one of two lens groups constituting the coupling lens to be capable of moving in the direction of an optical axis. The second driving device moves at least one of two lens groups constituting the coupling lens in the direction of an optical axis, and in this case, the optical element is moved so that spherical aberration caused on the converging optical system may be corrected appropriately, while monitoring signals from the sensor that detects the

state of light-converging of a light flux converged on the
information recording plane. It is possible to use an
actuator of a voice coil type and a piezo-actuator as the
second driving device. Further, the same effects as those in
(135) are exhibited.

(152) In the optical pick-up apparatus described in (151),
the light source emits light having a wavelength of 600 nm or
less, and axial chromatic aberration caused by refracting
action of each refracting interface in the converging optical
system and axial chromatic aberration caused by the
diffractive structure offset each other, thus, the same
effects as those in the invention described in Structure 2
are exhibited.

(153) In the optical pick-up apparatus described in (152),
axial chromatic aberration caused by the coupling lens, the
optical element on which the diffractive structure is
provided, and by the objective lens satisfies the following
expression, and thereby, the same effects as those in the
invention described in Structure 3 are exhibited;

$$|\triangle fB \cdot NA^2| \leq 0.25 \ \mu m \qquad (20)$$

wherein, NA represents the numerical aperture of the
prescribed objective lens on the subject side necessary for
recording and/or reproducing for an optical information
recording medium, and $\triangle fB$ represents a change (μm) of a

focus position of the composition system corresponding to the

change of + 1 nm in wavelength of the light source.

(154) In the optical pick-up apparatus described in one of

(151) to (153), the numerical aperture of the objective lens

on the image side that is necessary for conducting recording

and/or reproduction for the optical information recording

medium is 0.65 or more, and a thickness of the transparent

substrate of the optical information recording medium is 0.6

mm or less, thus, the same effects as those in the invention

described in (138) are exhibited.

(155) In the optical pick-up apparatus described in one of

(151) to (154), a lens group capable of moving in the

direction of an optical axis among lens groups constituting

the coupling lens has positive refracting power and satisfies

the following expression, thus, the same effects as those in

the invention described in Structure 5 are exhibited;

$$4 \leq f_{CP}/f_{OBJ} \leq 17 \qquad\qquad (21)$$

wherein f_{CP} represents focal length (mm) of a lens group that

can move in the direction of an optical axis and has positive

refracting power, and f_{OBJ} represents a focal length of the

objective lens.

(156) In the optical pick-up apparatus described in one of

(151) to (154), a lens group capable of moving in the

direction of an optical axis among lens groups constituting

the coupling lens has negative refracting power and satisfies
the following expression, thus, the same effects as those in
the invention described in Structure 6 are exhibited;

$$-20 \leq f_{CN}/f_{OBJ} \leq -3 \qquad (22)$$

wherein f_{CN} represents focal length (mm) of a lens group that
can move in the direction of an optical axis and has negative
refracting power, and f_{OBJ} represents a focal length of the
objective lens.

(157) In the optical pick-up apparatus described in one of
(151) to (156), the objective lens is of a construction of 1-
group and 1-element, and at least one surface thereof is
aspherical, thus, the same effects as those in the invention
described in (141) are exhibited.

(158) In the optical pick-up apparatus described in one of
(151) to (156), the objective lens is of a construction of 2-
group and 2-element, and at least two surfaces among the
first – third surfaces are aspherical, thus, the same effects
as those in the invention of (142) are exhibited.

(159) In an optical pick-up apparatus, an optical element on
which the diffractive structure is provided is made of
plastic materials, and therefore, the same effects as those
in the invention of (143) are exhibited.

(160) In the optical pick-up apparatus described in one of
(151) to (159), a lens group capable of moving in the

direction of an optical axis among lens groups constituting
the coupling lens is made of materials whose specific gravity
is not more than 2, and therefore, the same effects as those
in the invention described in Structure 10 are exhibited.

(161) In the optical pick-up apparatus described in one of
(151) to (160), a quantity of light of n-th order diffraction
light (n represents integers other than 0 and ±1) is greater
than that of diffraction light in any other order, and the
converging optical system stated above can converge, on an
information recording plane of the optical information
recording medium, n-th order diffraction light generated on
the diffractive structure in the course of information
recording and/or reproduction for the optical information
recording medium, and therefore, the same effects as those in
the invention described in Structure 11 are exhibited.

(162) In the optical pick-up apparatus described in one of
(151) to (161), deviation of spherical aberration caused on
each optical surface of the converging optical system by
deviation of oscillation wavelength of the light source is
corrected by moving at least one lens group constituting the
coupling lens in the direction of an optical axis, and
therefore, the same effects as those in the invention
described in Structure 12 are exhibited.

(163) In the optical pick-up apparatus described in one of
(151) to (161), the objective lens includes a lens formed
with at least one plastic material sheet, and deviation of
spherical aberration caused on each optical surface of a
converging optical system by changes of temperature and
humidity is corrected by moving at least one lens group
constituting the coupling lens in the direction of an optical
axis, thus, the same effects as those in the invention of
(147) are exhibited.

(164) In the optical pick-up apparatus described in one of
(151) to (161), deviation of spherical aberration caused by
variation of a thickness of a transparent substrate of the
information recording medium is corrected by moving at least
one lens group constituting the coupling lens, and thus, the
same effects as those in the invention of (148) are
exhibited.

(165) In the optical pick-up apparatus described in one of
(151) to (161), deviation of spherical aberration caused on
each optical surface of a converging optical system by
combination of at least two of deviation of oscillation
wavelength of the light source, changes of temperature and
humidity, and variation of a thickness of a transparent
substrate of the information recording medium, is corrected
by moving at least one lens group constituting the coupling

lens in the direction of an optical axis, and thereby, the

same effects as those in the invention represented by (149)

and described in Structure 15 are exhibited.

(166) In the optical pick-up apparatus described in one of

(151) to (165), the optical information recording medium has

structure wherein a plurality of transparent substrates and a

plurality of information recording layers are laminated

alternately in this order from the surface of the optical

information recording medium, the objective lens is moved in

the direction of an optical axis for focusing for information

recording and/or reproduction for each information recording

plane, and deviation of spherical aberration caused by a

difference of a thickness of the transparent substrate on

each information recording layer is corrected by moving at

least one lens group constituting the coupling lens in the

direction of an optical axis, and thereby, the same effects

as those in the invention of (150) are exhibited.

(167) A reproduction apparatus is equipped with an optical

pick-up apparatus described in either one of (151) - (166)

and is for recording voice and/or image, and/or for

reproducing voice and/or image.

The reproduction apparatus of (167) makes it possible

to conduct satisfactorily recording or reproduction of voice

and image for an advanced optical information recording

medium that is higher in terms of density and larger in terms of capacity than DVD, because a recording apparatus and a reproduction apparatus both for voice and image are equipped with the aforesaid optical pick-up apparatus.

(168) An optical pick-up apparatus has therein a light source, a coupling lens that changes a divergence angle of a divergent light emitted from the light source, and an objective lens that converges a light flux coming through the coupling lens on an information recording plane of an optical information recording medium, and conducting recording and/or reproduction of information for the optical information recording medium by detecting light coming from the optical information recording medium, wherein the coupling lens has a function to correct chromatic aberration of the objective lens, while the objective lens has an aspheric surface on at least one surface thereof and satisfies the following expression to obtain excellent image height characteristics;

$$1.1 \leq d1/f \leq 3$$

wherein, d1 represents an axial lens thickness and f represents a focal length.

(169) In the objective lens described in (168), the following expression is satisfied;

$$f/vd \leq 0.060$$

wherein, vd represents Abbe number.

(170) In the objective lens described in (168) or (169), the following expression is satisfied;

$1.40 \leq n$

wherein, n represents the index of refraction at the wavelength used.

(171) In the objective lens described in (170), the following expression is satisfied.

$1.40 \leq n \leq 1.85$

(172) In the objective lens described in one of (168) or (171), the following expression is satisfied;

$0.40 \leq r1/(n + f) \leq 0.70$

wherein, r1 represents the paraxial radius of curvature on the light source side.

(173) In the objective lens described in (168), it is preferable that the following expression is satisfied with respect to magnification m of a composite optical system;

$0.05 \leq |m| \leq 0.5$ (m < 0)

more preferably, $0.1 \leq |m| \leq 0.5$ (m < 0)

wherein, m represents a magnification of a composite optical system of an objective lens and a coupling lens.

When the magnification is not less than the lower limit of the conditional expression above, the composite optical system can be compact in size, and when it is not more than

the upper limit, aberration of the coupling lens turns out to be better.

(174) In the objective lens described in one of (168) to (173), it is preferable that deviation of spherical aberration caused on each optical surface of an optical system is corrected by moving the coupling lens in the direction of an optical axis. With regard to correction of the spherical aberration caused on a converging optical system of an optical pick-up apparatus, a divergence angle of a light flux entering the objective lens is changed by moving the coupling lens in the direction of an optical axis by an appropriate amount, when the spherical aberration of the optical system fluctuates to the "over" side or the "under" side. By virtue of this, the deviation of spherical aberration caused on the optical system can be canceled.

(175) In the objective lens described in (174), it is preferable that deviation of spherical aberration caused on each optical surface of an optical system by slight variation of an oscillation wavelength of the light source is corrected by moving the coupling lens in the direction of an optical axis. With regard to correction of spherical aberration that is caused on a converging optical system of an optical pick-up apparatus when an oscillation wavelength of a semiconductor laser of the light source is fluctuated, "over"

or "under" spherical aberration is caused on the optical

system when the oscillation wavelength is shifted from the

standard wavelength. A divergence angle of a light flux

entering the objective lens is changed by moving the coupling

lens in the direction of an optical axis by an appropriate

amount. By virtue of this, the deviation of spherical

aberration caused on the optical system can be canceled.

(176) In the objective lens described in (174), it is

preferable that deviation of spherical aberration caused on

each optical surface of an optical system by changes of

temperature and humidity is corrected by moving the coupling

lens in the direction of an optical axis. With regard to

correction of the spherical aberration that is caused on a

converging optical system of an optical pick-up apparatus

when temperature or humidity is changed, a divergence angle

of a light flux entering the objective lens is changed by

moving the coupling lens in the direction of an optical axis

by an appropriate amount, when "over" or "under" spherical

aberration is caused on an optical system by changes of

temperature or humidity. By virtue of this, the deviation of

spherical aberration caused on the optical system can be

canceled.

(177) In the objective lens described in (174), it is

preferable that deviation of spherical aberration caused on

each optical surface of an optical system by slight variation

of a thickness of a protective layer of the optical

information recording medium is corrected by moving the

coupling lens in the direction of an optical axis. With

regard to correction of the spherical aberration that is

caused on an optical system by an error of a thickness of the

protective layer of the optical information recording medium,

when there is an error that the protective layer turns out to

be thicker, "under" spherical aberration is caused when there

is an error that the "over" spherical aberration turns out to

be thinner in the optical system. In this case, a divergence

angle of a light flux entering the objective lens is changed

by moving the coupling lens in the direction of an optical

axis by an appropriate amount. By virtue of this, deviation

of spherical aberration caused on the optical system can be

canceled.

(178) In the objective lens described in (174), it is

preferable that deviation of spherical aberration caused on

each optical surface of an optical system by a combination of

at least two or more of slight deviation of an oscillation

wavelength of the light source, changes of temperature and

humidity, and slight deviation of a thickness of the

protective layer of the optical information recording medium,

is corrected by moving the coupling lens in the direction of

an optical axis. With regard to correction of spherical
aberration generated on the optical system by a combination
of at least two or more of slight deviation of an oscillation
wavelength of the laser, changes of temperature and humidity,
and slight deviation of a thickness of the protective layer
of the optical information recording medium, a divergence
angle of a light flux entering the objective lens is changed
by moving the coupling lens in the direction of an optical
axis by an appropriate amount, even in this case. By virtue
of this, deviation of spherical aberration caused on the
optical system can be canceled.

Further, it is preferable that deviation of spherical
aberration caused on each optical surface of an optical
system is corrected by moving the coupling lens in the
direction of an optical axis so that a distance between the
coupling lens and the objective lens may be increased when
spherical aberration of the optical system fluctuates to the
"over" side, and by moving the coupling lens in the direction
of an optical axis so that a distance between the coupling
lens and the objective lens may be decreased when spherical
aberration of the optical system fluctuates to the "under"
side. If the coupling lens is moved in the direction of an
optical axis so that the distance between the objective lens
and the coupling lens may be increased, divergent light

enters the objective lens more, compared with an occasion
before movement of the coupling lens, which makes it possible
to generate under spherical aberration on the objective lens.
Therefore, when over spherical aberration is caused on the
optical system for the reason stated above, if the coupling
lens is moved by an appropriate amount to increase the
distance between the objective lens and the coupling lens, it
is possible to just cancel the generated over spherical
aberration. On the contrary, if the coupling lens is moved
in the direction of an optical axis so that a distance
between the coupling lens and the objective lens may be
decreased, converged light enters the objective lens more,
compared with an occasion before movement of the coupling
lens, which makes it possible to generate over spherical
aberration on the objective lens. Therefore, when under
spherical aberration is generated for the aforesaid reason,
if the coupling lens is moved by an appropriate amount to
decrease the distance between the objective lens and the
coupling lens, it is possible to just cancel the generated
under spherical aberration.

It is further preferable to include a moving device
that moves the coupling lens in the direction of an optical
axis. On the actual optical pick-up apparatus, a coupling
lens is moved so that spherical aberration caused on an

optical system may be corrected appropriately, while an RF

signal of reproduction signal is being monitored. As a

moving device for the coupling lens, it is possible to use an

actuator of a voice coil type and a piezo-actuator.

The diffractive surface used in the present

specification means a configuration (or the surface) in which

a relief is provided on the surface of the optical element,

for example, the surface of the lens, and an action to change

an angle of the light rays by the diffraction is given to it,

and when there is an area in which the diffraction is

generated or an area in which the diffraction is not

generated, in one optical surface, it means the area in which

the diffraction is generated. As the shape of the relief, a

shape in which it is formed, for example, on the surface of

the optical element, as the almost concentric ring band

around the optical axis, and when its cross section is viewed

on the plane including the optical axis, it is known that

each ring band is formed as the saw-toothed shape, and such

the shape is included. Particularly, such the saw-tooth

shaped ring band structure is preferable.

In the present specifications, let it be assumed that

an objective lens means, in a narrow sense, a lens that is

arranged to be closest to an optical information recording

medium to face it and has a light-converging function in an

optical pick-up apparatus loaded with the optical information

recording medium, and means, in a broad sense, a lens group

that is capable of being driven by an actuator at least in

the direction of its optical axis together with the aforesaid

lens. The lens group in this case means at least one or more

of lenses. Therefore, in the present specifications,

numerical aperture NA of an objective lens on the optical

information recording medium side (image side) is numerical

aperture NA of a light flux which has emerged from the lens

surface positioned to be closest to the optical information

recording medium on the objective lens to the optical

information recording medium side. Further, the prescribed

numerical aperture necessary for recording and/or

reproduction of information for an optical information

recording medium in the present specifications is a numerical

aperture stipulated by the standard of each optical

information recording medium, or a numerical aperture of an

objective lens having the diffraction limit function capable

of obtaining a spot diameter necessary for recording or

reproducing information in accordance with a wavelength of

the light source to be used for each optical information

recording medium.

In the present specification, it is defined that the

converging optical system means a coupling lens which

includes at least an objective lens, and is arranged between
the light source and the objective lens, and which forms the
incident light flux into almost parallel light flux,
(including a collimator which forms the incident divergent
light into the parallel light flux). However, an aggregate
which is an aggregate of at least integrally functioned
optical elements such as the beam expander, which will be
described later, and an aggregate in which a part of optical
elements constituting the aggregate can transfer along the
optical axis direction, and a part of optical elements of the
aggregate are not included in the converging optical system
herein. In this connection, the coupling lens may be
composed of a plurality of lenses, and the structure in which
those lenses are separated and the other optical elements are
inserted between them, may also be allowable.

In the present specification, it is defined that the
beam expander means an aggregate of the optical elements such
as lenses (a group of optical elements such as lens group)
which can transfer at least the optical element such as one
lens along the optical axis direction, and thereby, can
change the divergent angle (including the divergent action,
convergent action) of the emitted light flux, and by which,
when almost parallel light flux is incident, almost parallel
light flux can be emitted. It is preferable that a plurality

of optical elements such as those lenses are integrated, and

when it is structured so that the optical element such as at

least one lens can transfer along the optical axis, a drive

means such as a transfer apparatus to practically conduct the

transfer may not be included in the beam expander.

In the beams expander of the present specification,

supposing that the diameter of almost parallel incoming light

flux is "a" and the diameter of almost parallel outgoing

light flux is "b", both cases that a < b (beam expanding

system) and a > b (beans compressing system) are included. Of

course, the case that a = b is included.

In the present specification, the means for correcting

the variation of the spherical aberration and the axial

chromatic aberration, means a structure in which a means for

correcting the variation of the spherical aberration, and a

means for correcting the axial chromatic aberration, have

both of 2 correction functions by a single means, for

example, one optical element or its aggregate (for example,

beam expander), and for example, the beam expander structured

by the specific Abbe's number positive lens and negative

lens, or the beam expander provided with the surface having

the diffractive structure, is listed. Further, in the

present specification, in the invention relating to the

optical pick-up apparatus, so far as specifically not being

regulated, it is defined that the focal length indicates a focal length to the oscillation wavelength of the light source which emits the light of the shortest oscillation wavelength in the used light source.

In the present specification, it is defined that the minute variation of the oscillation wavelength of the light source indicates the wavelength variation within the range of $\pm$ 10 nm to the oscillation wavelength of the light source. Further, in the present specification, for (finely)correcting each kind of aberrations, it is preferable that, when the spherical aberration is obtained, it is not larger than 0.07 λrms, which is so-called the diffraction limit performance, (herein, λ is the oscillation wavelength of the used light source), and further, considering the accuracy of the machine, it is more preferable to be not larger than 0.05 λrms. According to them, respectively appropriate spot sizes to various optical information recording media, can be obtained.

In the present specification, as the optical information recording medium (optical disk), the disk-shaped present optical information recording media and the next generation optical information recording media such as, for example, each kind of CDs such as CD-R, CD-RW, CD-Video, and

CD-ROM, each kind of DVDs such as DVD-ROM, DVD-RAM, DVD-R,

DVD-RW, and DVD-Video, or M, are also included. In this

connection, the transparent substrate used in the present

specification also includes a case where the thickness is 0,

that is, the transparent substrate does not exist.

In the present specification, the recording and the

reproducing of the information mean to record the information

onto the information recording plane of the optical

information recording media as described above, and to

reproduce the information recorded onto the information

recording plane. The optical pick-up apparatus of the

present invention may be the apparatus used for conducting

only the recording or only the reproducing, or may be the

apparatus used for conducting both of the recording and the

reproducing. Further, it may be the apparatus used for

conducting the recording for some optical information

recording medium, and for conducting the reproducing for the

other optical information recording medium, and may be the

apparatus used for conducting the recording or reproducing

for some optical information recording medium, and for the

other optical information recording medium, for conducting

the recording and the reproducing. In this connection, the

reproducing used herein, includes also only the reading of

the information.

The optical pick-up apparatus of the present invention can be mounted in the recording and/or reproducing apparatus of the audio and/or image, such as each kind of players or drives, or AV devices in which these are assembled, personal computers, or the other information terminal equipments.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an outline structural view of an optical pick-up apparatus according to the present embodiment.

Fig. 2 is an optical system structural view of a negative lens 5, positive lens 4 and objective lens 3 according to the example 1.

Fig. 3 is a spherical aberration view of the objective lens 3 according to the optical system of the example 1.

Fig. 4 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 2.

Fig. 5 is a spherical aberration view of the objective lens 3 according to the optical system of the example 2.

Fig. 6 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 3.

Fig. 7 is a spherical aberration view of the objective lens 3 according to the optical system of the example 3.

Fig. 8 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 4.

Fig. 9 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 4.

Fig. 10 a spherical aberration view of the objective lens 3 according to the optical system of the example 4.

Fig. 11 is a spherical aberration view of the objective lens 3 according to the optical system of the example 4.

Fig. 12 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 5.

Fig. 13 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 5.

Fig. 14 is a spherical aberration view of the objective lens 3 according to the optical system of the example 5.

Fig. 15 is a spherical aberration view of the objective lens 3 according to the optical system of the example 5.

Fig. 16 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 6.

Fig. 17 is a spherical aberration view of the objective lens 3 according to the optical system of the example 6.

Fig. 18 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 7.

Fig. 19 is a spherical aberration view of the objective lens 3 according to the optical system of the example 7.

Fig. 20 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 8.

Fig. 21 is a spherical aberration view of the objective lens 3 according to the optical system of the example 8.

Fig. 22 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 9.

Fig. 23 is a spherical aberration view of the objective lens 3 according to the optical system of the example 9.

Fig. 24 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 10.

Fig. 25 is a spherical aberration view of the objective lens 3 according to the optical system of the example 10.

Fig. 26 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 10.

Fig. 27 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 11.

Fig. 28 is a spherical aberration view of the objective lens 3 according to the optical system of the example 11.

Fig. 29 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 12.

Fig. 30 is an optical system structural view of the negative lens 5, positive lens 4 and objective lens 3 according to the example 12.

Fig. 31 is a spherical aberration view of the objective lens 3 according to the optical system of the example 12.

Fig. 32 is a spherical aberration view of the objective lens 3 according to the optical system of the example 12.

Fig. 33 is an optical system structural view of a collimator, negative lens 5, positive lens 4 and objective lens 3 according to the example 13.

Fig. 34 is a spherical aberration view of the objective lens 3 according to the optical system of the example 13.

Fig. 35 is an optical system structural view of the collimator, negative lens 5, positive lens 4 and objective lens 3 according to the example 14.

Fig. 36 is a spherical aberration view of the objective lens 3 according to the optical system of the example 14.

Fig. 37 is a view showing the optical system according to a different embodiment.

Fig. 38 a view showing the optical system according to a modified example of the present embodiment.

Fig. 39(a) is a sectional view typically showing the objective lens 3' which can be used for the optical pick-up apparatus of the present embodiment, and Fig. 39(b) is a front view viewed from the light source side.

Fig. 40 is an outlined structural view of an optical pickup apparatus according to the example 15.

Fig. 41 is a sectional view of a converging optical system according to the example 15.

Fig. 42 is a spherical aberration view of the converging optical system according to the example 15.

Fig. 43 is a sectional view of a converging optical system according to the example 16.

Fig. 44 is a spherical aberration view of the converging optical system according to the example 16.

Fig. 45 is an outlined structural view of an optical pickup apparatus according to the example 16.

Fig. 46 is a sectional view of a converging optical system according to the example 17.

Fig. 47 is a spherical aberration view of the converging optical system according to the example 17.

Fig. 48 is a sectional view of a converging optical system according to the example 18.

Fig. 49 is a spherical aberration view of the converging optical system according to the example 18.

Fig. 50 is a sectional view of a converging optical system according to the example 19.

Fig. 51 is a spherical aberration view of the converging optical system according to the example 19.

Fig. 52 is a sectional view of a converging optical system according to the example 20.

Fig. 53 is a spherical aberration view of the converging optical system according to the example 20.

Fig. 54 is an outlined structural view of an optical pickup apparatus according to the example 17.

Fig. 55 is an outlined structural view of an optical pickup apparatus according to the example 18.

Fig. 56 is a sectional view of a coupling lens and an objective lens according to the example 21.

Fig. 57 is a spherical aberration view of a coupling lens and an objective lens according to the example 21.

Fig. 58 is a sectional view of a coupling lens and an objective lens according to the example 22.

Fig. 59 is a spherical aberration view of a coupling lens and an objective lens according to the example 22.

Fig. 60 is a sectional view of a coupling lens and an objective lens according to the example 23.

Fig. 61 is a spherical aberration view of a coupling lens and an objective lens according to the example 23.

Fig. 62 is a view showing another embodiment of an optical pickup apparatus employing the objective lens of the present invention.

Fig. 63 is a sectional view showing an embodiment employing a refracting index distribution changing element according to the present invention.

Fig. 64 is a sectional view showing another embodiment employing a refracting index distribution changing element according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The optical pick-up apparatus to conduct the recording and/or reproducing of the information of the optical information recording medium of the present invention has a

light source, a converging optical system having the objective lens for converging the light flux emitted from the light source onto the information recording plane of the optical information recording medium so that the reproducing and/or recording of the information of the optical information recording medium can be conducted, and a photo detector for receiving the reflected light flux from the information recording plane. The converging optical system has at least one plastic lens, and a spherical aberration deviation (variation) correcting element (means) for correcting the deviation (variation) of the spherical aberration of the converging optical system. The numerical aperture at the image side of the objective lens is not smaller than 0.65 (preferably, not smaller than 0.75).

It is preferable that the light source is a semiconductor laser diode whose wavelength is not larger than 500 nm so as to be applied for the high density optical information recording medium. When the wavelength is such the short wavelength, it is preferable because the effect of the present invention becomes conspicuous.

It is preferable that the converging optical system has a coupling lens such as a collimator lens. The coupling lens may be composed of one lens, or one lens group, or comprises plurality of lenses or plurality of lens groups. Further, it

is preferable that the converging optical system can converge

the light flux of the wavelength λ emitted from the light

source onto the information recording plane of the optical

information recording medium within a predetermined numerical

aperture of the optical information recording medium in the

condition of the wavefront aberration not larger than 0.07 λ

rms. More preferably, the converging optical system can

converge the light flux in the condition of not larger than

0.05 λ rms.

The objective lens may be composed of one lens, or one

lens group, or comprises plurality of lenses or plurality of

lens groups. From the viewpoint of cost and the mounting

accuracy, it is preferable that the objective lens is

composed of a single lens. Further, it is preferable that

the objective lens has at least one aspheric surface.

The optical pick-up apparatus of the present invention

can be applied for a pickup apparatus to detect the reflected

light from the information recording plane and reproduces

and/or records the information.

The photo detector is a detector to detect the

reflected light, and an element to convert optical signals

into electronic signals such as PDIC is preferably used.

The plastic lens provided in the converging optical system may be an objective lens, or a coupling lens such as a collimator lens, or a lens constituting the spherical aberration deviation correcting element, or a lens constituting the axial chromatic aberration correcting element, or other lenses. Of course, all of the lenses in the converging optical system may be made of plastic.

The spherical aberration deviation (variation) correcting element may be composed of one optical element, or may have more than two optical elements.

Further, as examples of the deviation (variation) of the spherical aberration of the converging optical system to be corrected by the spherical aberration deviation (variation) correcting element, the following examples are listed.

The first example is the deviation (variation) of the spherical aberration accompanied by the change of the temperature and/or the humidity. For example, it is the variation of the spherical aberration generated accompanied by the change of at least one of the shape of the optical element (specifically, the optical element formed of plastic) and refractive index due to the environmental change between the temperature −30 to +85 °C, humidity 5 % to 90 %. The second example is the deviation (variation) of the spherical

aberration accompanied by the wavelength deviation

(variation) of the light source and/or the manufacturing

error of the wavelength of the light source. In this

connection, the [wavelength deviation (variation)] used

herein means that the wavelength of the light source of the

optical pick-up apparatus is minutely varied by about -10 nm

to +10 nm accompanied by the change of the temperature,

humidity or time, and the [manufacturing error of the

wavelength] means the error of the wavelength due to the

deviation for each of light sources at the time of the

production of the light source. The third example is the

deviation (variation) of the spherical aberration accompanied

by the deviation (variation) of the thickness of the

transparent substrate of the optical information recording

medium. The deviation (variation) of a thickness of the

transparent substrate includes a slight change in a thickness

of the transparent substrate (less than 100 μm preferably) of

one optical information recording medium, and it also

includes a difference of a thickness of a transparent

substrate between at least two kinds of optical information

recording medium, and the former is preferably meant. The

fourth example is the deviation (variation) of the spherical

aberration caused by the manufacturing errors of optical

element of the converging optical system such as a lens (for

example, errors of a form of the surface or errors of

thickness on an optical axis) aberration caused by, if a

spherical aberration deviation correcting element can correct

the spherical aberration deviation of fourth example

manufacturing precision does not need to be too severe, and

lens productivity can be enhanced.

Incidentally, when temperature rises, spherical

aberration is generated on an information recording plane in

the case of a refractive lens, in general, while, when

temperature falls, undercorrected spherical aberration is

generated. (However, when a objective lens having two lenses

is used, undercorrected spherical aberration is sometimes

generated when temperature rises.) When humidity rises,

undercorrected spherical aberration is generated on an

information recording plane in the case of a refractive lens,

in general, while, when humidity falls, overcorrected

spherical aberration is generated. When a wavelength of a

light source turns out to be long, overcorrected spherical

aberration is generated on an information recording plane in

the case of a refractive lens, in general, while, when a

wavelength of a light source turns out to be short,

undercorrected spherical aberration is generated. Further,

when a thickness of a transparent substrate of an optical

information recording medium is increased, overcorrected

spherical aberration is generated on an information recording

plane in the case of a refractive lens, in general, while,

when a thickness of a transparent substrate is decreased,

undercorrected spherical aberration is generated.

Further, it is preferable that spherical aberration

deviation correcting element can correct the spherical

aberration from 0.07 λ rms up to 0.2 λ rms to not larger than

0.07 λ rms. Further preferably, the spherical aberration

from 0.07 λ rms up to 0.5 λ rms can be corrected to not

larger than 0.07 λ rms.

The spherical aberration deviation (variation)

correcting element may have a movable element movable in the

optical axis direction, or may be composed of only a fixed

element. Further, the spherical aberration deviation

correcting element may be a combination of the movable

element and the fixed element.

A mode in which the spherical aberration deviation

(variation) correcting element has the movable element will

be described below. In the case where it has the movable

element, when the movable element moves in the optical axis

direction, the movable element can change the slope angle of

the marginal ray of an exit light flux by moving in an

optical axis direction, and the deviation (variation) of the

spherical aberration is corrected. In this connection, the movable element is preferably a lens or a lens group. More preferably, the movable element has a plastic lens. When the spherical averration deviation correcting element has the fixed element together with the movable element, the fixed element may also have a plastic lens. Further, preferably, the movable element has an aspheric lens having an aspheric surface on at least one surface. It may be a lens which has two aspheric surfaces. When it has the fixed element together with the movable element, the fixed element may also have an aspheric lens. Further, the optical pick-up apparatus preferably has a moving device to move the movable element in the direction of an optical axis. For example, the voice coil actuator or the piezoelectric actuator can be used as the moving device.

The first example having the movable element is an example in which the converging optical system has coupling lens, and at least one lens group in the lens group constructing the coupling lens is a movable element of the spherical aberration deviation (variation) correcting element. The coupling lens is composed of one or plural lens groups, and one lens group is composed of one or plural lenses. Incidentally, with regard to a "lens group" in the invention, one lens or a set of plural lenses each having the

same movement is regarded as one lens group, in the case of

lenses moving in the direction of an optical axis, and one

lens or a set of plural lenses which are in contact with

adjacent lenses is regarded as one lens group, in the case of

lenses which do not move in the direction of an optical axis.

Therefore, when two lenses which do not move in the direction

of an optical axis are present to be away from each other,

these lenses are regarded as different lens groups.

The one example of the frist example will be shown.

The converging optical system has the coupling lens having at

least 2 lens groups, and at least one lens group among at

least 2 lens groups constituting the coupling lens is a

movable element of a spherical aberration deviation

correcting element. Incidentally, all lens groups

constituting the coupling lens may move in the direction of

an optical axis, or, one or plural lens groups which do not

move in the direction of an optical axis may be used as a

fixed element. The example is shown in Fig. 40.

In this connection, in the lenses shown in Fig. 40, the

coupling lens is composed of 2 elements (lenses) in 2 groups.

The positive lens is the movable element of the spherical

aberration deviation correcting element. Of course, in the

example 1-1, the one lens group of coupling lens may be

composed of one lens, or a plurality of lenses. Further, in

one lens group, a plurality of lenses may be cemented or not

cemented. Further, in the example 1-1, the coupling lens

composed of 2 lens groups may be composed of the positive

lens group and the negative lens group, or may be composed of

the positive lens group and the positive lens group. In the

case of the coupling lens composed of the positive lens group

and negative lens group, the positive lens group may be the

movable element, or the negative lens group may be the

movable element. In this connection, it is preferable that

the coupling lens has a plastic lens. Particularly, the

movable element preferably has a plastic lens. Further, the

coupling lens has preferably the aspheric lens.

Particularly, the movable element preferably has the aspheric

lens.

In the example 1-1, when the coupling lens is composed

of two lens groups, it is preferable to move a movable

element so that a distance between two groups of the coupling

lens may be reduced, when spherical aberration varies in the

overcorrected deviation on the information recording plane,

and it is preferable to move a movable element so that a

distance between two groups of the coupling lens may be

extended when spherical aberration varies in the

undercorrected deviation on the information recording plane.

Next, the another example of the first example (example
1-2) will be shown. Also in this mode, the coupling lens is
the movable element of the spherical aberration deviation
correcting element. The coupling lens in the converging
optical system is composed of only one lens group, and the
one lens group of coupling lens is the movable element of the
spherical aberration deviation correcting element. That
example is shown in Fig. 62.

In this connection, in the coupling lens shown in Fig.
62, the coupling lens is composed of one element in one
group, and the element is a positive lens, and the positive
lens is the movable element of the spherical aberration
deviation correcting element. Of course, in the example 1-2,
one lens group of the coupling lens may be composed of one
lens, or may be composed of a plurality of lenses. Further,
in the one lens group, a plurality of lenses may be cemented,
or not cemented. In this connection, it is preferable that
the coupling lens has a plastic lens. Further, it is
preferable that the coupling lens has an aspheric lens.

In the example 1-2, it is preferable that the following
conditional expression is satisfied.

$0.05 \leqq |m| \leqq 0.5$ (m < 0)

m: the magnification of the combined system of the
objective lens and the coupling lens.

It is more preferable that the following conditional expression is satisfied.

0.1 ≦ |m| ≦ 0.5 (m < 0)

In the example 1-2, when spherical aberration varies in the overcorrected direction on the information recording plane, it is preferable that the coupling lens is moved so that a distance between the coupling lens and the objective lens may be extended, while when spherical aberration varies in the under corrected direction on the information recording plane, it is preferable that the coupling lens is moved so that a distance between the coupling lens and the objective lens may be reduced.

An example of an embodiment which is more preferable in the first example having therein a movable element will be shown below. A wavelength of a light source is not more than 500 nm, at least one lens in the coupling lens has a diffractive surface having a ring-shaped diffractive structure, the lens having a diffractive surface is a plastic lens, and the movable element is a plastic lens and an objective lens is a plastic lens.

Next, the second example having the movable element will be shown. The second example is an example in which the converging optical system has a coupling lens, and has the positive lens group having at least one positive lens and the

negative lens group having at least one negative lens,
between the coupling lens and the objective lens, and at
least one of the positive lens group and the negative lens
group is the movable element of the spherical aberration
deviation correcting element. Further, its one example is
shown in Fig. 1.

In the second example, the positive lens group and the
negative lens group may be composed of respectively one lens,
or may be composed of a plurality of lenses. Further, in
respective lens groups, a plurality of lenses may be
cemented or not cemented. In this connection, it is
preferable that the positive lens group, or the negative lens
group has the plastic lens. More preferably, the movable
lens groups have the plastic lens. Further, it is preferable
that the positive lens group or the negative lens group has
the aspheric lens. More preferably, the movable lens groups
have the aspheric lens.

Further, in the second example, the converging optical
system may have a beam expander, and the beam expander may
also have the positive lens group and the negative lens
group. Of course, in this case also, at least one of the
positive lens group and the negative lens group is the
movable element of the spherical aberration deviation
correcting element. It is preferable that the beam expander

has a moving device to move the movable element. For

example, the voice coil actuator or the piezoelectric

actuator can be used as the moving device.

In this connection, in the optical system shown in Fig.

1, the coupling lens having positive refractive power is

composed of one element in one group, and the one element is

a positive lens and the beam expander is provided between the

coupling lens and the objective lens, and the beam expander

is composed of one negative lens and one positive lens, and

the negative lens is the movable element of the spherical

aberration deviation correcting element.

In the second example, it is preferable that the

following conditional expression is satisfied.

$$| \, fP/fN \, | \geqq 1.1$$

fP: the focal distance of the positive lens group (when the

positive lens group has the diffractive surface, fP is the

total focal distance in which the refractive power and the

diffractive power are combined together)

fN: the focal distance of the negative lens group (when the

negative lens group has the diffractive surface, fN is the

total focal distance in which the refractive power and the

diffractive power are combined together).

More preferably, $| \, fP/fN \, | \geqq 1.2$.

Further preferably, 2.0 $\geq$| fP/fN | $\geq$ 1.2.

Further more preferably, 2.0 $\geq$| fP/fN | $\geq$ 1.3.

In the example 2, in which a beam expander is composed
of two lens groups including a positive lens group and a
negative lens group, when spherical aberration varies in the
overcorrected deviation on the information recording plane,
it is preferable that the movable element is moved so that a
distance between the two lens groups of the beam expander is
reduced, while, when spherical aberration varies in the
undercorrected deviation on the information recording plane,
it is preferable that the movable element is moved so that a
distance between the two lens groups of the beam expander may
be extended.

Incidentally, a preferable embodiment in the second
example having therein a movable element will be shown below.
A wavelength of a light source is not more than 500 nm, at
least one lens among positive lens group or a negative lens
group has a diffractive surface having a ring-shaped
diffractive structure, a lens having a diffractive surface is
a plastic lens, and the movable element is a plastic lens and
an objective lens is a plastic lens.

Next, there will be described an occasion wherein a
spherical aberration deviation correcting element has no

movable element but has only a fixed element which does not
move in the direction of an optical axis. It is preferable
that the fixed element is represented by an element whose
refractive index distribution in the direction perpendicular
to an optical axis is variable. For example, there is given
a liquid crystal element. An example of a preferable fixed
element whose refractive index distribution is variable will
be shown below.

Fig. 63 shows the example 1. Between the objective
lens and the collimator lens, there is arranged refractive
index distribution variable element 21 whose refractive index
distribution is variable, as shown in Fig. 63.

As refractive index distribution variable element 21,
it is possible to use an element wherein electrode layers a,
b and c which are electrically connected each other and are
transparent optically, for example, and refractive index
distribution variable layers d and e which are insulated
electrically from the electrode layers a, b and c and change
in terms of refractive index distribution in accordance with
impressed voltage are laminated alternatively, and optically
transparent electrode layers a, b and c are divided into
plural areas.

In Fig. 63, when deviation of spherical aberration is
detected, voltage is impressed on electrode layers a, b and c

by driving means 22 for refractive index distribution

variable element 21 so that refractive index of refractive

index distribution variable layers d and e may be changed

depending on locations, and a phase of light emerging from

refractive index distribution variable element 21 is

controlled so that deviation of spherical aberration may be

zero.

Fig. 64 shows an example of another refractive index

distribution variable element. Refractive index distribution

variable element 23 in Fig. 64 is equipped with liquid

crystal element 23a on which liquid crystal molecules are

arranged in order in the arbitrary X direction on a plane

perpendicular to an optical axis and with liquid crystal

element 23b on which liquid crystal molecules are arranged in

order in the Y direction perpendicular to the X direction on

a plane perpendicular to an optical axis. Liquid crystal

element 23a and liquid crystal element 23b are laminated

alternatively with an inbetween of glass base board 23c, and

1/2 wavelength plate 23d is arranged between inner glass

substrate 23c.

In Fig. 64, when deviation of spherical aberration is

detected, deviation of spherical aberration is corrected by

impressing voltage on each of liquid crystal element 23a and

liquid crystal element 23b both of refractive index

distribution variable element 23 with driving means 22, and

thereby, by controlling component in X direction and

component in Y direction of light emerging from refractive

index distribution variable element 23 independently.

Refractive index distribution variable element 21 and

refractive index distribution variable element 23 shown

respectively in Fig. 63 and Fig. 64 make it possible to

constitute a converging optical system which has no movable

element and has structure that is mechanically simple.

Further, it is preferable that the converging optical

system has the axial chromatic aberration correcting element

to correct the axial chromatic aberration of the converging

optical system. Particularly, in the case where the

converging optical system has the plastic lens, particularly

the objective lens is the plastic lens, a problem of the

axial chromatic aberration becomes conspicuous, and it is

preferable that converging optical system has the axial

chromatic aberration correcting element. Further, in the

case that the wavelength of the light source is 500 nm or

less, it is preferable to comprise the axial chromatic

aberration correcting element, since the axial chromatic

aberration becomes larger. In this connection, the axial

chromatic aberration correcting element and the spherical

aberration deviation correcting element may be composed of

the same optical elements or members, or may be composed of different optical elements or members. One of the axial chromatic aberration correcting element and the spherical aberration deviation correcting element may be incorporated in the other one. Further, a part of the spherical aberration deviation correcting element and a part of the axial chromatic aberration correcting element may be the same optical element. Further, the axial chromatic aberration correcting element may be composed of one optical element, or may have more than 2 optical elements.

It is preferable that in case that the axial chromatic aberration correcting element comprises at least one positive lens group (including only one lens or plural lenses) having one positive lens and at least one negative lens group (including only one lens or plural lenses) having one negative lens, and the following condition is satisfied.

$vdP > vdN$

vdP: an average of Abbe's numbers of d lines of all the positive lenses of the conversing optical system

vdN: an average of Abbe's numbers of d lines of all the negative lenses of the conversing optical system

Further preferably, the following condition is satisfied.

vdP > 55

vdN < 35

Further, in the case of the above second example in which the spherical aberration deviation correcting element has the movable element, as the axial chromatic aberration correcting element, it is preferable that the following conditional expression is satisfied.

$$\Delta d \cdot |\ fP/fN\ |/\Delta vd \leqq 0.05$$

Δd: the movement amount (mm) of the movable element when the information is recorded or reproduced for one information recording plane of one arbitrary optical information recording medium for which the information can be recorded or reproduced,

fP: the focal length (mm) of the positive lens group (in this connection, when the diffractive surface is provided on the positive lens group, the total focal length in which the refractive power and the diffractive power are combined),

fN: the focal length (mm) of the negative lens group (in this connection, when the diffractive surface is provided on the negative lens group, the total focal length in which the refractive power and the diffractive power are combined),

Δvd: the difference between the maximum value of Abbe's number of the positive lens and the minimum value of Abbe's

number of the negative lens, in the positive lens group and the negative lens group.

Incidentally, it is preferable that Δd is defined as follows.

Δd: The movement amount (mm) of a movable element necessary for correcting deviation of spherical aberration caused by temperature rise of 30°C from standard temperature (preferably, temperature within a range of 15 - 35°C) to 0.05 λ rms or less

Further, in the case of the above second example in which the spherical aberration deviation correcting element has the movable element, as the axial chromatic aberration correcting element, it is preferable that the following conditional expression is satisfied.

$\Delta d \cdot | fP/fN | \leqq 0.5$

Further, it is preferable that the axial chromatic aberration correcting element has the diffractive surface having the ring-shaped diffractive structure. It is preferable because the correction can be more intensely conducted, as compared to a case in which the axial chromatic aberration is corrected by the regulation of Abbe's number. The diffractive surface may be provided on the objective lens, or coupling lens, or on the other lens, or on the

optical element other than lenses. Of course, diffractive
surface may also be provided on the optical element comprised
in the spherical aberration deviation correcting element.
Further, a diffractive surface may be provided on one side or
both sides of the lens. The optical element provided with
the diffractive surface becomes the axial chromatic
aberration correcting element.

Further, when axial chromatic aberration correcting
element has a positive lens group having at least one
positive lens (having only one lens or plural lenses), a
negative lens group having at least one negative lens (having
only one lens or plural lenses) and further, at least one
diffractive surface, it is preferable that Abbe's number of d
line for each of all positive lenses of the converging
optical system is not more than 70, and Abbe's number of d
line for each of all negative lenses of the converging
optical system is not less than 40.

When providing a axial chromatic aberration correcting
element having a diffractive surface, it is preferable that
the following conditional expression is satisfied, when "a"
represents the axial chromatic aberration caused by
reflective index dispersion of a converging optical system
(induding objective lens and other optical elements) when a

wavelength of a light source varies (preferably, varies by -
10 nm to +10 nm),
and "b" represents the sum total of the axial chromatic
aberrations caused by both refractive index dispersion of the
converging optical system and a diffractive surface.

$|a| > |b|$

Further, it is preferable that the diffractive surface
suppresses axial chromatic aberration caused by an objective
lens when a wavelength of a light source varies. In
particular, it is preferable that axial chromatic aberration
is suppressed when a wavelength slightly varies by -10 nm to
+10 nm. Further, when a wavelength of a light source varies,
it is preferable that axial chromatic aberration caused by
the diffractive surface and axial chromatic aberration caused
by refractive index dispersion of a converging optical system
offset each other for the most part (preferably, perfectly).
Further, when the wavelength of a light source increases, it
is preferable that the diffractive surface has wavelength
characteristics which make the back focus to be short.
Further, it is preferable that the diffractive surface
corrects spherical aberration so that spherical aberration
caused by refractive index dispersion of a converging optical
system when a wavelength of a light source varies may be made
to approach the spherical aberration of the converging

optical system in the case of the standard wavelength. To be
more concrete, it is preferable that undercorrected spherical
aberration caused by the diffractive surface when a
wavelength of a light source increases, corrects
overcorrected spherical aberration caused by refractive index
dispersion of the converging optical system. It is further
preferable that spherical aberration caused by the
diffractive surface when a wavelength of a light source
varies and spherical aberration caused by the refractive
index dispersion of a converging optical system offset each
other for the most part (preferably, perfectly). When the
wavelength of a light source increases, it is preferable that
the diffractive surface has spherical aberration
characteristics which make spherical aberration to be
undercorrected. Further, it is preferable that the
diffractive surface generates an amount of nth-ordered
diffracted ray (n represents integers other than 0, ± 1) to be
greater than that of anyother ordered diffracted ray.

Further, it is preferable that the axial chromatic
aberration correcting element satisfies the following
conditional expression.

P2 < P1 < P3

P1: the paraxial power of the axial chromatic aberration
correcting element at the wavelength of light source,

P2: the paraxial power of the axial chromatic aberration correcting element at the wavelength which is 10 nm shorter than the wavelength of the light source,

P3: the paraxial power of the axial chromatic aberration correcting element at the wavelength which is 10 nm longer than the wavelength of the light source.

When the axial chromatic aberration correcting element has a diffractive surface, each of the paraxial powers P1, P2, P3 stated above are the total paraxial powers wherein paraxial refractive power and paraxial diffractive power are combined.

When the objective lens is composed of one lens, it is preferable that the following conditional expression is satisfied.

$$1.1 \leqq d1/f \leqq 3$$

d1: the axial lens thickness of the objective lens,

f: the focal distance of the objective lens

More preferably, $1.2 \leqq d1/f \leqq 2.3$, and further preferably, $1.4 \leqq d1/f \leqq 1.8$.

The condition mentioned above is especially appropriate in the objective lens of an optical pickup apparatus used for reproducing or recording of information for only optical

information recording medium or media whose necessary

numerical aperture is 0.65 or more.

Further, it is preferable that the objective lens is

the plastic lens.

As the material of the optical element in the present

invention, the following is listed as the preferable

materials. Further, it is more preferable that the optical

element, particularly the movable element comprised of the

spherical aberration deviation correcting element, or the

objective lens is made of the following materials. The

material whose specific gravity is not larger than 2.0. The

material whose saturated water absorption is not larger than

0.5 %. The material, for the light of the wavelength of the

light source, whose internal transmitance at the 3 mm

thickness is not smaller than 85 %. Plastics satisfying one

or more of the above conditions.

Further, the optical pick-up apparatus of the present

invention may be made so that it conducts the recording and

/or reproducing of the information of only one kind of

optical information recording medium, or it can also conduct

the recording and /or reproducing of the information of more

than 2 kinds of different optical information recording

media.

For example, when the optical pick-up apparatus can conduct the recording and /or reproducing of the information of 2 kinds of optical information recording media, it is preferable that the optical pick-up apparatus has the first light source to emit the first light flux of the wavelength of $\lambda 1$ to conduct the reproducing and/or recording of the first optical information recording medium, and the second light source to emit the second light flux of the wavelength of $\lambda 2$ ($\lambda 1 \neq \lambda 2$) to conduct the reproducing and/or recording of the second optical information recording medium. The converging optical system converges at least a portion of the first light flux onto the information recording plane of the first optical information recording medium so that the information of the first optical information recording medium can be recorded and/or reproduced, and converges at least a portion of the second light flux onto the information recording plane of the second optical information recording medium so that the information of the second optical information recording medium can be recorded and/or reproduced.

In this connection, the different kind of optical information recording medium includes cases in which the recording density of the information is different, the necessary numerical aperture for recording and/or reproducing

is different, the wavelength used for recording and/or reproducing of the information is different, the thickness of the transparent substrate is different, or the combination of these cases. As a preferable example, the combination in which $\lambda 1 < \lambda 2$, and the recording density of information of the first optical information recording medium is higher than the density of the second information recording medium, and the transparent substrate thickness of the first optical information recording medium is thinner than the transparent substrate thickness of the second optical information recording medium, and the necessary numerical aperture for recording and/or reproducing information of the first optical information recording medium is larger than the necessary numerical aperture for recording and/or reproducing information of the second optical information recording medium, is listed.

Especially, when a thickness of the first transparent substrate of the first optical information recording medium is different from a thickness of second transparent substrate of the second optical information recording medium, the spherical aberration deviation correcting element may correct variation of spherical aberration caused by a difference between a thickness of the first transparent substrate and that of the second transparent substrate.

As the structure to record and/or reproduce 2 kinds of different optical information recording media by one optical pick-up apparatus, various modes can be applied.

As the first example, a mode in which the spherical aberration deviation correcting element having the movable element of the spherical aberration deviation correcting element is used, is listed. When the movable element of the spherical aberration deviation correcting element is moved in the optical axis direction, the slop angle of the marginal ray of the incident light flux into the objective lens is changed, and the deviation of the spherical aberration generated by the difference of the transparent substrate thickness of 2 kinds of optical information recording media is corrected, and the light flux is converged onto respective information recording planes so that the information can be recorded and/or reproduced.

The second example is a mode in which the diffractive surface is used. The diffractive surface is provided on the optical element in the converging optical system, and by using the difference of the position of the focus point of the diffracted light by difference of the wavelengths of 2 light sources, the spherical aberration caused by the difference of the transparent substrate thickness of 2 kinds of the optical information recording media is corrected, and

the light fluxes are converged onto respective information
recording planes so that the information can be recorded
and/or reproduced. The diffractive surface may be provided
on the coupling lens, or the objective lens, or may be
provided also on the other optical elements.

The third example is a mode in which the optical
element such as an objective lens having at least 3 divided
surfaces formed concentric circularly around the optical axis
is used. When the divided surface closest to the optical
axis is the first divided surface, its outside divided
surface is the second divided surface, and its outside
surface is the third divided surface, the light flux passed
through the first divided surface and the third divided
surface is converged onto the information recording plane of
the first optical information recording medium so that the
information can be recorded and/or reproduced. On the one
hand, the light flux passed through the first divided surface
and the second divided surface is converged onto the
information recording plane of the second optical information
recording medium whose necessary predetermined numerical
aperture is smaller than the first optical information
recording medium, so that the information can be recorded
and/or reproduced.

        Incidentally, on the outside of the third divided

surface, one or plural divided surfaces may be further

provided.

        The fourth example is an embodiment wherein an

objective lens has, on its at least one surface, ring-shape

stepped sections which divide an incident light flux through

refraction effect into a ring-shaped light flux (in this

case, 1st, 2nd, … k-th light fluxes in the order from the

optical axis side to its outside) in quantity of k (k ≥ 3),

spherical aberration component of wavefront aberration of the

1st and k-th light fluxes in the position of the best image

plane made by the 1st and k-th light fluxes is 0.07 λ1 rms or

less, at least two light fluxes among the 2nd to (k-1)-th

fluxes form a position of an apparent best image plane at the

location different from the position of the best image plane

made by the 1st and k-th light fluxes, and at the position of

the best image plane made by the 1st and k-th light fluxes,

wavefront aberration of light in each of 1st to k-th light

fluxes passing through the prescribed numerical aperture on

the image side of the objective lens needed for recording

and/or reproducing of information of the first optical

information recording medium is almost mi λ1 (mi is an

integer and i = 1, 2, …, k).

Further, two or more of above four examples may be combined. In all of the above 4 examples, when the light flux of the first light source of the wavelength $\lambda 1$ is converged onto the information recording plane of the first optical information recording medium, it is preferable that, within the predetermined numerical aperture for recording and/or reproducing information of the first optical information recording medium, the wave front aberration on the information recording plane is not larger than 0.07 $\lambda 1$ rms, and more preferably, not larger than 0.05 $\lambda 1$ rms. Further, when the light flux of the second light source of the wavelength $\lambda 2$ is converged onto the information recording plane of the second optical information recording medium, it is preferable that, within the predetermined numerical aperture for recording and/or reproducing information of the second optical information recording medium, the wave front aberration on the information recording plane is not larger than 0.07 $\lambda 2$ rms, and more preferably, not larger than 0.05 $\lambda 2$ rms.

When predetermined numerical aperture NA1 for recording and/or reproducing information of the first optical information recording medium is greater than predetermined numerical aperture NA2 for recording and/or reproducing

information of the second optical information recording

medium, and when a light flux of the second light source

having wavelength of $\lambda 2$ is converged on an image recording

plane of the second optical information recording medium, it

is preferable that light fluxes within NA2 are converged so

that wavefront aberration on the information recording plane

is 0.07 $\lambda 2$ rms or less, and light fluxes within NA1 are

converged so that wavefront aberration on the information

recording plane may be greater than 0.07 $\lambda 2$ rms. It is more

preferable to be not more than 0.05 $\lambda 2$ rms within NA2 and to

be not less than 0.2 $\lambda 2$ rms within NA1.

Incidentally, when two kinds or more kinds of different

optical information recording media are subjected to

recording and/or reproducing by one optical pickup apparatus,

and these optical information recording media include one

whose necessary numerical aperture for recording and/or

reproducing information is less than 0.65, and when an

objective lens is composed of one lens, it is preferable that

the following conditional expression is satisfied;

$$0.7 \leqq d1/f \leqq 2.4$$

wherein, d1 represents an axial lens thickness of the

objective lens, and f represents a focal length of the

objective lens at $\lambda 1$.

It is preferable that the objective lens satisfying the conditional expression stated above has at least one aspheric surface.

Further, the optical information recording medium may have a plurality of information recording planes on the one side of optical information recording medium. For example, there may be listed the structure that a transparent substrate and a information recording layer are alternately piled in a plurality of stacked layers in the order from the same light flux incident side surface. In this case, the converging optical system can converge the light flux emitted from the light source onto respective information recording planes of the optical information recording medium so that the information of the optical information recording medium can be recorded and/or reproduced.

For the structure to record and/or reproduce information of the optical information recording medium having a plurality of information recording planes, various modes can be applied. For example, a mode in which the spherical aberration deviation correcting element having the movable element is used, is listed. When the movable element of the spherical aberration deviation correcting element is moved in the optical axis direction, the slope angle of the marginal ray of the incident light flux into the objective

lens is changed, and the deviation of the spherical aberration generated by the position of each information recording plane is corrected, and the light flux is converged onto respective information recording plane so that the information can be recorded and/or reproduced.

Further, in the above description, when the light flux of the wavelength λ is converged onto each information recording plane of the optical information recording medium, it is preferable that, within a predetermined numerical aperture for recording and/or reproducing information of the optical information recording medium, the wave front aberration on the information recording plane is not larger than 0.07 λ rms, and more preferably, not larger than 0.05 λ rms.

Further, it is preferable that the optical pickup apparatus of the invention has a spherical aberration deviation detection means that detects deviation of spherical aberration caused in a converging optical system. Based on the results of the detection by this detection means, the deviation of spherical aberration can also be corrected by moving a movable element when the spherical aberration deviation detection means has the movable element, or by changing refractive index when the spherical aberration deviation correcting element has a means whose refractive

index distribution in the direction perpendicular to an optical axis is variable.

Further, the optical information recording medium recording and/or reproducing apparatus of the present invention in order to record and/or reproduce the information of the optical information recording medium, has the optical pick-up apparatus, as described above, of the present invention. Preferably, it has a spindle motor or a power source.

The aspherical surface used in the present embodiment, is expressed by the following [Equation 1]. Where, X is the axis in the optical axis direction, h is the axis in the perpendicular direction to the optical axis, and the advancing direction of the light is positive, r is the paraxial radius of curvature, κ is a conical coefficient, and A_{21} is the aspherical surface coefficient.

[Equation 1]

$$X = \frac{h^2/r}{1 + \sqrt{1 - (1+\kappa)h^2/r^2}} + \sum_{i=2}^{\infty} A_{2i} h^{2i}$$

The spherical surface used in the present embodiment is expressed by [Equation 2] as the optical path difference function.

[Equation 2]

$$\phi_b = \sum_{i=1}^{\infty} b_{2i} h^{2i}$$

Referring to the drawings, the preferable embodiments of the present invention will be described below. Fig. 1 is an outline structural view of the optical pick-up apparatus according to the present embodiment. In Fig. 1, the first light source 11 to conduct the recording and/or reproducing for the first optical information recording medium 24, and the second light source whose wavelength is different from the first light source 11 to conduct the recording and/or reproducing for the second optical information recording medium 23 are provided, and coupling lenses 21 and 22 to convert the divergent angles of the divergent light fluxes emitted from respective light sources, a beam splitter 62 which is an optical path composition means for making the light fluxes emitted from respective light sources advance in almost the same direction, an objective lens 3 to light-converge the light flux from the beam splitter 62 onto the information recording plane 5 of the optical information recording medium, and light detectors 41 and 42 to light-receive the reflected light from the optical information recording medium, are provided. In the drawing, numeral 8 is a diaphragm, numeral 9 is a cylindrical lens, numerals 71 and 72 are 1/4 wavelength plates, numeral 15 is a coupling lens

to reduce the divergent angle of the divergent light flux
from the light source 11, numeral 16 is a concave lens, and
numeral 17 is a hologram to separate the reflected light
flux.

Further, in the present embodiment, as a means for
correcting the variation of the spherical aberration of the
objective lens 3 and a divergent angle changing means, a
negative lens 5 and a positive lens 4 which are arranged in
order from the light source side and an actuator 7 are
provided, (hereinafter, these are also called a spherical
aberration correction means, and a divergent angle changing
means). The actuator 7 functions as a transfer apparatus to
change the slope angle of the marginal ray of the light flux
by moving the negative lens 5 as an optical element in the
optical axis direction. Further, relating to the present
embodiment, in examples 1 to 14 showing a specific portion of
the optical system, an example of so-called beam expander
structured by the transferable negative lens 5 and the
positive lens 4, is sometimes expressed as the spherical
aberration correction means. In this connection, numeral 6
is an actuator to dive the objective lens 3 in the optical
axis direction for focusing. It is defined that the first
light source 11 can emit the laser light of wavelength $\lambda 1 =$

405 nm, and the second light source 12 can emit the laser

light of wavelength $\lambda 2$ = 655 nm.

In the examples being described below, in examples 1,

2, 11, 12, the diffractive surface is provided on the

objective lens 3 and the axial chromatic aberration is

corrected, and in examples 3 to 5, a specific material is

used for the negative lens 5 and the positive lens 4 and the

axial chromatic aberration is corrected, and in examples 6 to

8, 13 and 14, the diffractive surface is provided on at least

one of the negative lens 5 and the positive lens 4, and the

axial chromatic aberration of the objective lens 3 is

corrected, and in examples 9 and 10, the axial chromatic

aberration of the objective lens 3 is corrected by the

synergetic effect of the specific material of the negative

lens 5 and the positive lens 4 and the diffractive surface

provided on the positive lens 4. Further, examples 4, 5 and

12 are examples to conduct the recording or reproducing of

the information by using the same optical system for the

different optical information recording media. In this

connection, in the following examples of the objective lens

3, it is formed by using the plastic material whose saturated

water absorption is not larger than 0.01 %, and whose

internal transmitance by the light flux of the light source

wavelength 400 nm is 90.5 %, and whose permeability by the

light flux of the light source wavelength 700 nm is 92 %.

Further, in the following example, in the example in which

only the first light source 11 in the present embodiment

shown in Fig. 1 is used, although a drawing of the specific

embodiment is neglected, generally, in the pick-up apparatus

of Fig. 1, for example, a mode in which the second light

source 12, coupling lens 22, beam splitter 62, light detector

42, 1/4 wavelength plate 72 and hologram 17 are removed, can

be applied. Each of examples will be described below.

[Example 1]

The data for the optical system composed of the

negative lens 5, positive lens 4, and objective lens 3 in the

example 1 is shown in Table 1. In this connection, in the

data shown hereinafter, the powers of 10 (for example, 2.5 x

10^{-3}) is expressed by using E (for example, 2.5 x E-3).

Further, the first order light by the diffraction of the

diffractive surface expressed by the rotation symmetry

polynomial means the light in which an angle of the ray of

light changes in the converging direction after the

diffraction.

Table 1

Example 1
λ1 405 nm
NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1	Spherical	-604.711	0.800	1.91409	23.8
2	aberration	7.532	1.000		
3	correction	8.122	1.200	1.50717	81.6
4	means	-11.199	1.000		
5 (Diaphragm)		∞	0.000		
6 (Aspheric surface 1, diffractive surface 1)	Objective lens	1.233	2.688	1.52524	56.5
7 (Aspheric surface 2)		-0.931	0.334		
8	Transparent	∞	0.100	1.51949	30.0
9	substrate	∞	0.000		

Aspheric surface 1
K   -6.8440E-01
A_4 1.7085E-02
A_6 2.4417E-03
A_8 1.4011E-03
A_{10} 3.9966E-04
A_{12} -2.0375E-04
A_{14} 1.8903E-05
A_{16} 2.6231E-05
A_{18} 2.3047E-05
A_{20} -1.4976E-05

Aspheric surface 2
K   -22.173426
A_4 0.345477
A_6 -0.821245
A_8 0.890651
A_{10} -0.391613
A_{12} -0.252257E-03
A_{14} -0.109061E-09
A_{16} -0.166822E-10
A_{18} -0.250470E-11
A_{20} -0.370377E-12

Diffractive surface 1
B_2 -7.0001E-03

Fig. 2 is an optical system structural view of the

negative lens 5, positive lens 4, and objective lens 3

according to the example 1. Fig. 3 is a spherical aberration

view according to the objective lens 3. In the example 1,

the information is recorded or reproduced by the combination

of the first light source 11 of the wavelength 405 nm and the

image side numerical aperture NA 0.85 of the objective lens

3. In the present example, as the material of the negative

lens 5 and the positive lens 4 of the means for correcting

the variation of the spherical aberration, the materials of

vdN = 23.8, vdP = 81.6 are respectively selected, and

further, by providing the diffractive surface on the surface

of the light source side of the objective lens 3, the axial

chromatic aberration generated in the objective lens 3 is

corrected. Further, in the present example, fN =-8.13 (mm),

fP = 9.48 (mm), and f = 1.765 (mm) and fD = 71.483 (mm).

In the present example, the correction of the variation

of the spherical aberration at the time of the minute

variation of the oscillation wavelength of the light source

(hereinafter, simply called also as the wavelength variation)

or the temperature change, can be conducted as follows. In

the case of the present example, when the wavelength becomes

large, or the temperature rises, in the objective lens 3, the

overcorrected spherical aberration is generated. In such the

case, when the negative lens 5 is moved along the optical

axis by the actuator 7, and the interval between the negative

lens 5 and the positive lens 4 is reduced, the undercorrected

spherical aberration can be generated. When the negative

lens 5 is moved by an appropriate amount, the overcorrected

spherical aberration can be cancelled, and as can clearly be

seen from Table 2 showing the result of the spherical

aberration, the spherical aberration of the whole optical

system becomes fine.

Table 2

Example 1

Image height characteristic WFE rms		$Y = 0$ μm $Y = 10$ μm	0.004λ (1.00 mm) 0.011λ
Wavelength characteristic WFE rms	+ 10 nm	$Y = 0$ μm Δf_B (μm)	0.005λ (0.75 mm) +0.47
	- 10 nm	$Y = 0$ μm Δf_B (μm)	0.011λ (1.27 mm) -0.64
Temperature characteristic WFE rms	+ 30 °C - 30 °C	$Y = 0$ μm	0.008λ (0.80 mm) 0.024λ (1.22 mm)

Note) The figure in the parentheses in the Table expresses

the interval between the negative lens and the positive lens

of the spherical aberration correction means, and the

divergent angle changing means.

[Example 2]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 2 is shown in Table 3.

Table 3

Example 2
$\lambda 1$ 405 nm
NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	νd
1	Spherical aberration correction means	-6.551	0.800	1.61949	30.0
2		5.582	1.000		
3		8.542	1.200	1.52524	56.5
4		-5.364	1.000		
5 (Diaphragm)		∞	0.000		
6 (Aspheric surface 1, diffractive surface 1)	Objective lens	1.233	2.688	1.52524	56.5
7 (Aspheric surface 2)		-0.931	0.334		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Aspheric surface 1
K -6.8440E-01
A_4 1.7085E-02
A_6 2.4417E-03
A_8 1.4011E-03
A_{10} 3.9966E-04
A_{12} -2.0375E-04
A_{14} 1.8903E-05
A_{16} 2.6231E-05
A_{18} 2.3047E-05
A_{20} -1.4976E-05

Aspheric surface 2
K -22.173426
A_4 0.345477
A_6 -0.821245
A_8 0.890651
A_{10} -0.391613
A_{12} -0.252257E-03
A_{14} -0.109061E-09
A_{16} -0.166822E-10
A_{18} -0.250470E-11
A_{20} -0.370377E-12

Diffractive surface 1
B_2 -7.0001E-03

Fig. 4 is an optical system structural view of the negative lens 5, positive lens 4, and objective lens 3 according to the example 2. Fig. 5 is a spherical aberration view according to the objective lens 3. In the example 2, the information is recorded or reproduced by the combination of the first light source 11 of the wavelength 405 nm and the image side numerical aperture NA 0.85 of the objective lens 3. In the example 2, as the material of the negative lens 5 and the positive lens 4 of the means for correcting the variation of the spherical aberration, the materials of $vdN = 30.0$, $vdP = 56.5$ are respectively selected, and further, by providing the diffractive surface on the surface of the light source side of the objective lens 3, the axial chromatic aberration generated in the objective lens 3 is corrected. Further, in the present example, $fN = -4.75$ (mm), $fP = 6.47$ (mm), and $f = 1.765$ (mm) and $fD = 71.483$ (mm).

Because the correction of the variation of the spherical aberration at the time of the wavelength variation or temperature change in the present example is the same as in the example 1, the explanation is neglected. As can clearly be seen from Table 4 showing the correction result of the spherical aberration, the spherical aberration at the time of the wavelength variation or temperature change becomes fine. Further, as the objective lens 3 and the means

for correcting the variation of the spherical aberration,
when the plastic material is used for the negative lens 5 and
the positive lens 4, the weight reduction of the optical
system and the reduction of the burden onto the movable
mechanism are attained.

Table 4

Example 2

Image height characteristic WFE rms		$Y = 0$ μm	0.005λ (1.00 mm)
		$Y = 10$ μm	0.009λ
Wavelength characteristic WFE rms	+ 10 nm	$Y = 0$ μm Δf_B (μm)	0.005λ (0.91 mm) +1.30
	- 10 nm	$Y = 0$ μm Δf_B (μm)	0.009λ (1.10 mm) -1.60
Temperature characteristic WFE rms	+ 30 °C	$Y = 0$ μm	0.007λ (0.88 mm)
	- 30 °C		0.017λ (1.13 mm)

Note) The figure in the parentheses in the Table expresses
the interval between the negative lens and the positive lens
of the spherical aberration correction means, and the
divergent angle changing means.

[Example 3]

The data relating to the optical system composed of the
negative lens 5, positive lens 4 and objective lens 3 in the
example 3 is shown in Table 5.

Table 5

Example 3
λ1 405 nm
NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1	Spherical	-20.486	0.800	1.91409	23.8
2	aberration	14.729	1.000		
3	correction	26.278	1.200	1.50717	81.6
4	means	-7.040	1.000		
5 (Diaphragm)		∞	0.000		
6 (Aspheric surface 1)	Objective lens	1.225	2.845	1.52524	56.5
7 (Aspheric surface 2)		-0.763	0.292		
8	Transparent	∞	0.100	1.61949	30.0
9	substrate	∞	0.000		

Aspheric surface 1
K   -0.699712
A_4 0.166009E-01
A_6 0.209051E-02
A_8 0.157932E-02
A_{10} 0.212509E-03
A_{12} -0.344184E-03
A_{14} 0.119417E-04
A_{16} 0.577745E-04
A_{18} 0.409189E-04
A_{20} -0.257292E-04

Aspheric surface 2
K   -20.033672
A_4 0.331327
A_6 -0.881378
A_8 0.965015
A_{10} -0.412771
A_{12} -0.252257E-03
A_{14} -0.110756E-09
A_{16} -0.168921E-10
A_{18} -0.253030E-11
A_{20} -0.370376E-12

Fig. 6 is an optical system structural view of the

negative lens 5, positive lens 4, and objective lens 3

according to the example 3. Fig. 7 is a spherical aberration
view according to the objective lens 3. In the example 3,
the information is recorded or reproduced by the combination
of the first light source 11 of the wavelength 405 nm and the
image side numerical aperture NA 0.85 of the objective lens
3. In the example 3, as the material of the negative lens 5
and the positive lens 4, by respectively selecting the
materials of vdN = 23.8 and vdP = 81.6, the axial chromatic
aberration is corrected. Further, in the present example, fN
=-9.27 (mm), fP = 11.08 (mm), and f = 1.765 (mm).

Because the correction of the variation of the
spherical aberration at the time of the wavelength variation
or temperature change in the present example is the same as
in the example 1, the explanation is neglected. As can
clearly be seen from Table 6 showing the correction result of
the spherical aberration, the spherical aberration at the
time of the wavelength variation or temperature change
becomes fine. Further, when the plastic material is used for
the objective lens 3, the weight reduction of the optical
system and the reduction of the burden onto the movable
mechanism are attained.

Table 6

Example 3

Image height characteristic WFE rms		Y = 0 μm Y = 10 μm	0.010λ (1.00 mm) 0.011λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm Δf_B (μm)	0.025λ (0.87 mm) +1.81
	- 10 nm	Y = 0 μm Δf_B (μm)	0.021λ (1.21 mm) -2.03
Temperature characteristic WFE rms	+ 30 °C - 30 °C	Y = 0 μm	0.028λ (0.70 mm) 0.024λ (1.28 mm)

Note) The figure in the parentheses in the Table expresses the interval between the negative lens and the positive lens of the spherical aberration correction means, and the divergent angle changing means.

[Example 4]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 4 is shown in Table 7.

Table 7

Example 4
λ1 405 nm
λ2 655 nm
NA1 0.85
NA2 0.65

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Divergent angle changing means	-4.511	0.800	1.5949	30.0
2 (Aspheric surface 2)		5.332	(Variable interval 1)		
3 (Aspheric surface 3)		8.748	1.200	1.52524	56.5
4 (Aspheric surface 4)		-5.817	1.700		
5 (Diaphragm)		∞	0.700		
7 (Aspheric surface 5, diffractive surface 1)	Objective lens	1.180	2.518	1.52524	56.5
8 (Aspheric surface 5)		-1.146	(Variable interval 2)		
9	Transparent substrate	∞	(Variable interval 3)	1.61949	30.0
10		∞			

	λ1	λ2
Variable interval 1	2.271	0.602
Variable interval 2	0.405	0.261
Variable interval 3	0.100	0.600

Aspheric surface 1
K   -1.82245E+00
A_4 1.91843E-03
A_6 1.53453E-03
A_8 -3.74714E-03
A_{10} -3.98906E-05
A_{12} -4.92552E-13

Aspheric surface 2
K   -3.59130E-01
A_4 -3.68216E-04
A_6 3.35772E-04
A_8 -1.59195E-03
A_{10} -7.62648E-04
A_{12} -4.15896E-10

Aspheric surface 3
K   -4.37805E+00
A_4 -7.92779E-04
A_6 1.00408E-03
A_8 2.25086E-04
A_{10} -1.35761E-04
A_{12} -5.87062E-08
A_{14} -4.46993E-05
A_{16} -1.66320E-06
A_{18} -9.66153E-07
A_{20} 1.05818E-06

Aspheric surface 4
K   -1.59857E-01
A_4 7.04289E-05
A_6 2.47603E-04
A_8 3.22371E-04
A_{10} 6.12332E-05
A_{12} -5.31635E-05
A_{14} -3.38725E-05
A_{16} 1.91316E-06
A_{18} -2.94735E-08
A_{20} 6.23600E-07

Aspheric surface 5
K   -7.83080E-01
A_4 2.01730E-02
A_6 -1.84080E-03
A_8 7.06210E-03
A_{10} -6.87170E-04
A_{12} -9.64340E-04
A_{14} 6.64990E-05
A_{16} 2.60470E-04
A_{18} 4.70690E-05
A_{20} -4.45290E-05

Aspheric surface 6

K	$-2.03154E+01$
A_4	$2.67833E-01$
A_6	$-4.80343E-01$
A_8	$3.68667E-01$
A_{10}	$-1.19103E-01$
A_{12}	$4.67297E-03$
A_{14}	$9.98218E-10$
A_{16}	$1.22952E-10$
A_{18}	$1.57221E-11$
A_{20}	$1.92406E-12$

Diffractive surface 1

b_2	$-1.00000E-06$
b_4	$-2.33560E-03$
b_6	$-7.29050E-04$
b_8	$9.81200E-04$
b_{10}	$5.06860E-05$
b_{12}	$1.88310E-04$
b_{14}	$-1.02330E-04$
b_{16}	$5.97500E-05$
b_{18}	$2.65550E-05$
b_{20}	$-1.09350E-05$

Figs. 8 and 9 are optical system structural views of the negative lens 5, positive lens 4, and objective lens 3 according to the example 4. Figs. 10 and 11 are spherical aberration views according to the objective lens 3 when the information is recorded or reproduced respectively for the different optical information recording media. The example 4 is an example of the optical pick-up apparatus by which the information is recorded or reproduced by the combination of the first light source 11 of the wavelength 405 nm and the optical information recording medium whose transparent substrate thickness is 0.6mm, or by the combination of the second light source 11 of the wavelength 655 nm and the

optical information recording medium whose transparent

substrate thickness is 0.6mm, by using the same optical

system. In the example 4, as the material of the negative

lens 5 and the positive lens 4, by respectively selecting the

materials of vdN = 30.0 and vdP = 56.5, the axial chromatic

aberration is corrected. Further, in the present example, fN

=-3.82 (mm), fP = 6.85 (mm), and f1 = 1.765 (mm) and fD1 =

5000000.02 (mm). In this connection, the focal length of the

objective lens at the oscillation wavelength $\lambda 2$ =655 nm is f2

=1.804.

In the example 4, the variation of the spherical

aberration generated due to the difference of the transparent

substrate thickness in more than two kinds of optical

information recording media, is corrected by changing the

interval of the divergent angle changing means (corresponds

to a means for correcting the variation of the spherical

aberration of the present invention, or a means for

correcting the variation of the spherical aberration and the

axial chromatic aberration) composed of one negative lens 5

and one positive lens 4 in the order from the light source

side. Further, by providing the diffractive surface on the

surface on the light source side of the objective lens 3, the

spherical aberration is more finely corrected. Further, the

spherical aberration deviation of converging optical system

at the time of the wavelength variation of the light source

or the temperature change is also finely corrected by

changing the interval of the divergent angle changing means.

That is, as can clearly be seen from Table 8, by changing the

interval between the negative lens 5 and the positive lens 4

to an appropriate interval, the spherical aberration

deterioration of the objective lens 3 at the time of the

substrate thickness change, or at the time of the wavelength

variation and temperature change, is finely corrected.

Further, when the plastic material is used for the objective

lens 3, negative lens 5 and positive lens 4, the weight

reduction of the optical system and the reduction of the

burden onto the movable mechanism are attained.

Table 8

Example 4

			405 nm NA 0.85	655 nm NA 0.65
Image height characteristic WFE rms		$Y = 0\ \mu m$ $Y = 10\ \mu m$	0.008λ (2.27 mm) 0.025λ	0.008λ (0.60 mm) 0.030λ
Wavelength characteristic WFE rms	+ 10 nm	$Y = 0\ \mu m$ $\Delta f_B\ (\mu m)$	0.019λ (2.24 mm) +3.57	0.005λ (0.62 mm) +0.47
	- 10 nm	$Y = 0\ \mu m$ $\Delta f_B\ (\mu m)$	0.021λ (2.31 mm) +3.57	0.01λ (0.59 mm) +0.47
Temperature characteristic WFE rms	+ 30 °C - 30 °C	$Y = 0\ \mu m$	0.028λ (2.15 mm) 0.028λ (2.44 mm)	0.018λ (0.63 mm) 0.006λ (0.58 mm)

Note) The figure in the parentheses in the Table expresses the interval between the negative lens and the positive lens of the spherical aberration correction means, and the divergent angle changing means.

[Example 5]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 5 is shown in Table 9.

Table 9

Example 5
λ1 405 nm
λ2 655 nm
NA1 0.85
NA2 0.65

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Divergent angle changing means	-8.096	1.000	1.61949	30.0
2 (Aspheric surface 2)		8.634	(Variable interval 1)		
3 (Aspheric surface 3)		11.647	1.500	1.52524	56.5
4 (Aspheric surface 4)		-8.791	1.800		
5 (Diaphragm)		∞	-0.800		
7 (Aspheric surface 5, diffractive surface 1)	Objective lens	1.979	4.322	1.52524	56.5
8 (Aspheric surface 5)		-1.853	(Variable interval 2)		
9	Transparent substrate	∞	(Variable interval 3)	1.61949	30.0
10		∞			

	λ1	λ2
Variable interval 1	2.367	1.520
Variable interval 2	0.684	0.503
Variable interval 3	0.100	0.600

Aspheric surface 1
K   -8.49544E-01
A_4 2.60023E-04
A_6 -1.81862E-05
A_8 -5.43678E-05
A_{10} -4.51719E-06
A_{12} -4.84352E-07

Aspheric surface 2

K	-1.51200E+00
A_4	-2.95477E-04
A_6	-6.00121E-05
A_8	-9.38876E-07
A_{10}	-9.20091E-06
A_{12}	-4.37732E-07

Aspheric surface 3

K	-1.41587E+00
A_4	-1.44673E-04
A_6	-9.36888E-06
A_8	6.82686E-07
A_{10}	1.03613E-07
A_{12}	1.93933E-09
A_{14}	-5.32563E-09

Aspheric surface 4

K	-6.16512E-01
A_4	1.03046E-04
A_6	2.00275E-06
A_8	-8.66334E-07
A_{10}	1.56881E-07
A_{12}	-1.06594E-08
A_{14}	1.06582E-09

Aspheric surface 5

K	-7.77500E-01
A_4	4.52960E-03
A_6	-1.03310E-04
A_8	1.54300E-04
A_{10}	-7.93870E-06
A_{12}	-2.71240E-06
A_{14}	-3.51620E-09
A_{16}	9.02610E-08
A_{18}	6.04590E-09
A_{20}	-1.79290E-09

Aspheric surface 6

K	-2.31402E+01
A_4	5.47424E-02
A_6	-3.25565E-02
A_8	8.11386E-03
A_{10}	-8.45883E-04
A_{12}	6.59378E-05
A_{14}	-1.21099E-06
A_{16}	-2.46113E-06
A_{18}	-1.12315E-06
A_{20}	9.53156E-11

Diffractive surface 1
b_2 -5.88260E-07
b_4 -2.47940E-04
b_6 -8.68800E-05
b_8 1.67950E-05
b_{10} -4.00170E-07
b_{12} -5.69670E-07
b_{14} -9.95240E-08
b_{16} 2.40370E-08
b_{18} 3.46480E-09
b_{20} -5.18490E-10

Figs. 12 and 13 are optical system structural views of
the negative lens 5, positive lens 4, and objective lens 3
according to the example 5. Figs. 14 and 15 are spherical
aberration views according to the objective lens 3 when the
information is recorded or reproduced respectively for the
different optical information recording media. The example 5
is an example of the optical pick-up apparatus by which the
information is recorded or reproduced by the combination of
the first light source 11 of the wavelength 405 nm and the
optical information recording medium whose transparent
substrate thickness is 0.6mm, or by the combination of the
second light source 11 of the wavelength 655 nm and the
optical information recording medium whose transparent
substrate thickness is 0.6mm, by using the same optical
system. In the example 5, as the material of the negative
lens 5 and the positive lens 4, by respectively selecting the
materials of vdN = 30.0 and vdP = 56.5, the axial chromatic

aberration is corrected. Further, in the present example, fN =-6.59 (mm), fP = 9.85 (mm), and f1 = 3.011 (mm) and fD1 = 849964.33 (mm). In this connection, the focal length of the objective lens at the oscillation wavelength $\lambda 2$ =655 nm is f2 =3.076.

In the same manner as in the example 4, as can clearly be seen from Table 10, by changing the interval between the negative lens 5 and the positive lens 4 to an appropriate interval, the spherical aberration deviation of converging optical system at the time of the substrate thickness change, or at the time of the wavelength variation and temperature change, is finely corrected. Further, when the plastic material is used for the objective lens 3, negative lens 5 and positive lens 4, the weight reduction of the optical system and the reduction of the burden onto the movable mechanism are attained.

Table 10

Example 5

			405 nm NA 0.85	655 nm NA 0.65
Image height characteristic WFE rms		Y = 0 μm	0.008λ (2.36 mm)	0.001λ (1.52 mm)
		Y = 10 μm	0.021λ	0.019λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm Δf$_B$ (μm)	0.044λ (2.35 mm) +4.90	0.002λ (1.57 mm) +0.82
	- 10 nm	Y = 0 μm Δf$_B$ (μm)	0.045λ (2.39 mm) -5.47	0.002λ (1.47 mm) -0.86
Temperature characteristic WFE rms	+ 30 °C	Y = 0 μm	0.061λ (2.22 mm)	0.006λ (1.57 mm)
	- 30 °C		0.081λ (2.55 mm)	0.004λ (1.45 mm)

Note) The figure in the parentheses in the Table expresses the interval between the negative lens and the positive lens of the spherical aberration correction means, and the divergent angle changing means.

In this connection, even when the light flux incident to the negative lens 5 of the means for correcting the variation of the spherical aberration is not only the parallel light, but also the divergent light or convergent light, the optical system of the present invention can also be applied in the same manner. Further, although not shown in the drawing in the present example, a coupling lens to change the divergent angle of the light flux from the light source can be provided between the light source and the spherical aberration correction means. When the diffractive surface is added to such the coupling lens and the diffractive structure has characteristic in which the back

focus becomes short on the long wavelength side, the axial chromatic aberration generated in the objective lens can be corrected.

The coupling lens used for the optical system according to the present invention is not limited to the above modes, but when it is a coupling lens as described in Japanese No. 2000-060843 by the present applicant, the axial chromatic aberration generated in the objective lens 3 can be more finely corrected.

Further, when a beam shaping element by which the astigmatic difference of the light flux from the light source is relieved, and the almost circular light flux can be incident to the spherical aberration correction means, is provided between the coupling lens and the means for correcting the variation of the spherical aberration (negative lens 5, positive lens 4), the divergent angle of the light flux from the coupling lens is changed by the focal point movement due to the temperature or humidity change, and the astigmatism is generated by the beam shaping element. In order to suppress this, when the coupling lens as disclosed in Japanese No. 2000-053858 is used, the generation of the astigmatism by the beam shaping element can be suppressed.

In this connection, in the examples 4 and 5, the spherical aberration views for the optical information

recording medium in the light source wavelength 655 nm, and the transparent substrate thickness 0.6 mm, are shown up to NA 0.65. However, in this case, the light flux passing though all of the diaphragms determined by the light source wavelength 405 nm, NA 0.85 is incident to the objective lens 3. The light flux more than NA 0.65 which does not contribute to the image formation, is made a flare component by using the effect of the diffractive surface provided on the objective lens 3, thereby, the spot diameter is not excessively squeezed on the optical information recording plane, and the detection of the unnecessary signal on the light receiving element of the optical pick-up apparatus can be prevented.

[Example 6]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 6 is shown in Table 11.

Table 11

Example 6
λ1 405 nm
NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Spherical aberration correction means	-5.556	0.800	1.52524	56.5
2 (Aspheric surface 2)		5.279	1.000		
3 (Aspheric surface 3)		12.098	1.200	1.52524	56.5
4 (Aspheric surface 4, diffractive surface 1)		-6.085	1.000		
5 (Diaphragm)		∞	-0.000		
6 (Aspheric surface 5)	Objective lens	1.225	2.845	1.52524	56.5
7 (Aspheric surface 6)		-0.763	0.292		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Aspheric surface 1
K   -5.72580E-02
A_4 -1.45908E-03
A_6 6.52770E-03
A_8 -2.53887E-03
A_{10} -3.22205E-03

Aspheric surface 2
K   4.07593E+00
A_4 3.63395E-03
A_6 -2.26920E-03
A_8 -2.83908E-03
A_{10} -3.04265E-04

Aspheric surface 3
K   5.32508E+00
A_4 1.06266E-04
A_6 -5.48799E-05
A_8 1.47470E-04
A_{10} 4.06608E-04
A_{12} -1.27769E-04

Aspheric surface 4
K   1.13730E+00
A_4 -1.46440E-03
A_6 4.40310E-04
A_8 2.47800E-04
A_{10} 4.40280E-05
A_{12} -1.33270E-05

Aspheric surface 5
K   -6.99712E-01
A_4 1.66009E-02
A_6 2.09051E-03
A_8 1.57932E-03
A_{10} 2.12509E-04
A_{12} -3.44184E-04
A_{14} 1.19417E-05
A_{16} 5.77745E-05
A_{18} 4.09189E-05
A_{20} -2.57292E-05

Aspheric surface 6
K   -2.00337E+01
A_4 3.31327E-01
A_6 -8.81378E-01
A_8 9.65015E-01
A_{10} -4.12771E-01
A_{12} -2.52257E-04
A_{14} -1.10756E-10
A_{16} -1.68921E-11
A_{18} -2.53030E-12
A_{20} -3.70376E-13

Diffractive surface 1
b_2 -1.00000E-02
b_4 4.93850E-04
b_6 2.43430E-04
b_8 1.12150E-04
b_{10} -2.73490E-05

Fig. 16 is an optical system structural view of the
negative lens 5, positive lens 4, and objective lens 3
according to the example 6. Fig. 17 is a spherical
aberration view according to the objective lens 3. In the
example 6, the information is recorded or reproduced by the

combination of the first light source 11 of the wavelength

405 nm and the image side numerical aperture NA 0.85 of the

objective lens 3. In the example 6, when the diffractive

surface is added to the surface of the optical information

recording medium side of the objective lens 4, and the

diffractive structure has characteristics in which the back

focus becomes short on the long wavelength side, the axial

chromatic aberration generated in the objective lens 3 is

corrected. Further, in the present example, $fN = -0.503$ (mm),

$fP = 6.81$ (mm), and $f1 = 1.765$ (mm).

Because the correction of the variation of the

spherical aberration at the time of the wavelength variation

of the light source or temperature change in the present

example is the same as in the example 1, the explanation is

neglected. As can clearly be seen from Table 12, the

spherical aberration at the time of the wavelength variation

or temperature change becomes fine. Further, when the

plastic material is used for the objective lens 3, negative

lens 5 and positive lens 4, the weight reduction of the

optical system and the reduction of the burden onto the

movable mechanism are attained.

Table 12

Example 6

Image height characteristic WFE rms		Y = 0 μm Y = 10 μm	0.008λ (1.00 mm) 0.017λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm Δf_B (μm)	0.009λ (0.94 mm) +3.01
	− 10 nm	Y = 0 μm Δf_B (μm)	0.009λ (1.06 mm) −3.71
Temperature characteristic WFE rms	+ 30 °C − 30 °C	Y = 0 μm	0.005λ (0.93 mm) 0.016λ (1.07 mm)

Note) The figure in the parentheses in the Table expresses

the interval between the negative lens and the positive lens

of the spherical aberration correction means, and the

divergent angle changing means

[Example 7]

The data relating to the optical system composed of the

negative lens 5, positive lens 4 and objective lens 3 in the

example 7 is shown in Table 13.

Table 13

Example 7

λ1 405 nm

NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Spherical aberration correction means	-6.790	0.800	1.52524	56.5
2 (Aspheric surface 2)		4.293	1.000		
3 (Aspheric surface 3, diffractive surface 1)		6.555	1.200	1.52524	56.5
4 (Aspheric surface 4, diffractive surface 2)		-10.777	1.000		
5 (Diaphragm)		∞	0.000		
6 (Aspheric surface 5)	Objective lens	1.225	2.845	1.52524	56.5
7 (Aspheric surface 6)		-0.763	0.292		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Aspheric surface 1

K	6.34005E-01
A_4	-8.04474E-04
A_6	3.26482E-03
A_8	-1.10780E-03
A_{10}	-2.17617E-03

Aspheric surface 2

K	5.90931E-01
A_4	1.44067E-03
A_6	-3.12725E-03
A_8	-2.20735E-03
A_{10}	-3.12725E-05

Aspheric surface 3

K	9.31840E-01
A_4	1.47940E-04
A_6	-2.30680E-05
A_8	3.05100E-04
A_{10}	-4.13730E-05

Aspheric surface 4
K   0.00000E+00
A_4 -1.11870E-03
A_6 6.80430E-04
A_8 3.66720E-04
A_{10} -2.55160E-05

Aspheric surface 5
K   -6.99712E-01
A_4 1.66009E-02
A_6 2.09051E-03
A_8 1.57932E-03
A_{10} 2.12509E-04
A_{12} -3.44184E-04
A_{14} 1.19417E-05
A_{16} 5.77745E-05
A_{18} 4.09189E-05
A_{20} -2.57292E-05

Aspheric surface 6
K   -2.00337E+01
A_4 3.31327E-01
A_6 -8.81378E-01
A_8 9.65015E-01
A_{10} -4.12771E-01
A_{12} -2.52257E-04
A_{14} -1.10756E-10
A_{16} -1.68921E-11
A_{18} -2.53030E-12
A_{20} -3.70376E-13

Diffractive surface 1
b_2 -8.00000E-03
b_4 2.66130E-04
b_6 7.45750E-05
b_8 -1.58010E-04
b_{10} 4.67190E-05

Diffractive surface 2
b_2 -8.00000E-03
b_4 -2.59880E-04
b_6 3.77670E-04
b_8 5.66990E-05
b_{10} -4.26270E-05

Fig. 18 is an optical system structural view of the
negative lens 5, positive lens 4, and objective lens 3

according to the example 7. Fig. 19 is a spherical

aberration view according to the objective lens 3. In the

example 7, the information is recorded or reproduced by the

combination of the first light source 11 of the wavelength

405 nm and the image side numerical aperture NA 0.85 of the

objective lens 3. In the example 7, when the diffractive

surfaces are added to the both surfaces of the negative lens

5 and the positive lens 4, and the diffractive structure have

characteristics in which the back focus becomes short on the

long wavelength side, the axial chromatic aberration

generated in the objective lens 3 is corrected. Further, in

the present example, fN =-4.89 (mm), fP = 5.83 (mm), and f1 =

1.765 (mm).

Because the correction of the variation of the

spherical aberration at the time of the wavelength variation

of the light source or temperature change in the present

example is the same as in the example 1, the explanation is

neglected. As can clearly be seen from Table 14, the

spherical aberration at the time of the wavelength variation

or temperature change becomes fine. Further, when the

plastic material is used for the objective lens 3, negative

lens 5 and positive lens 4, the weight reduction of the

optical system and the reduction of the burden onto the

movable mechanism are intended.

Table 14

Example 7

Image height characteristic WFE rms		Y = 0 µm Y = 10 µm	0.008λ (1.00 mm) 0.017λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 µm Δf_B (µm)	0.007λ (0.95 mm) +0.83
	- 10 nm	Y = 0 µm Δf_B (µm)	0.010λ (1.05 mm) -1.21
Temperature characteristic WFE rms	+ 30 °C - 30 °C	Y = 0 µm	0.008λ (0.96 mm) 0.019λ (1.05 mm)

Note) The figure in the parentheses in the Table expresses the interval between the negative lens and the positive lens of the spherical aberration correction means, and the divergent angle changing means.

[Example 8]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 8 is shown in Table 15.

Table 15

Example 8

λ1 405 nm

NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1, diffractive surface 1)	Spherical aberration correction means	-4.781	0.800	1.52524	56.5
2 (Aspheric surface 2, diffractive surface 2)		6.136	1.000		
3 (Aspheric surface 3, diffractive surface 3)		23.371	1.200	1.52524	56.5
4 (Aspheric surface 4, diffractive surface 4)		-5.587	1.000		
5 (Diaphragm)		∞	0.000		
6 (Aspheric surface 5)	Objective lens	1.225	2.845	1.52524	56.5
7 (Aspheric surface 6)		-0.763	0.292		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Aspheric surface 1

K	-5.09350E-02
A_4	-2.56160E-04
A_6	2.73940E-03
A_8	-6.04320E-04
A_{10}	-1.04120E-03
A_{12}	-8.54300E-04

Aspheric surface 2

K	2.61840E+00
A_4	1.40260E-03
A_6	-9.46360E-04
A_8	-1.03170E-03
A_{10}	-7.00650E-04
A_{12}	1.59290E-04

Aspheric surface 3

K	$1.48200E+01$
A_4	$1.08520E-04$
A_6	$-2.99390E-05$
A_8	$-5.09390E-05$
A_{10}	$-9.76740E-05$
A_{12}	$-5.01720E-01$

Aspheric surface 4

K	$7.68210E-01$
A_4	$-7.75160E-04$
A_6	$2.57520E-04$
A_8	$2.11770E-04$
A_{10}	$2.31350E-05$
A_{12}	$-1.82460E-05$

Aspheric surface 5

K	$-6.99712E-01$
A_4	$1.66009E-02$
A_6	$2.09051E-03$
A_8	$1.57932E-03$
A_{10}	$2.12509E-04$
A_{12}	$-3.44184E-04$
A_{14}	$1.19417E-05$
A_{16}	$5.77745E-05$
A_{18}	$4.09189E-05$
A_{20}	$-2.57292E-05$

Aspheric surface 6

K	$-2.00337E+01$
A_4	$3.31327E-01$
A_6	$-8.81378E-01$
A_8	$9.65015E-01$
A_{10}	$-4.12771E-01$
A_{12}	$-2.52257E-04$
A_{14}	$-1.10756E-10$
A_{16}	$-1.68921E-11$
A_{18}	$-2.53030E-12$
A_{20}	$-3.70376E-13$

Diffractive surface 1

b_2	$-5.00000E-03$
b_4	$3.72180E-04$
b_6	$-1.28520E-03$
b_8	$2.68410E-04$
b_{10}	$1.32790E-05$

Diffractive surface 2
b_2 -5.00000E-03
b_4 1.24620E-03
b_6 1.57800E-04
b_8 9.32920E-05
b_{10} -2.48990E-04

Diffractive surface 3
b_2 -5.00000E-03
b_4 -8.23030E-05
b_6 6.12980E-05
b_8 7.98370E-05
b_{10} -5.34800E-05

Diffractive surface 4
b_2 -5.00000E-03
b_4 -5.11460E-04
b_6 6.47470E-05
b_8 3.77610E-05
b_{10} -1.42650E-05

Fig. 20 is an optical system structural view of the
negative lens 5, positive lens 4, and objective lens 3
according to the example 8. Fig. 21 is a spherical
aberration view according to the objective lens 3. In the
example 8, the information is recorded or reproduced by the
combination of the first light source 11 of the wavelength
405 nm and the image side numerical aperture NA 0.85 of the
objective lens 3. In the example 8, when the diffractive
surfaces are added to the both surfaces of the negative lens
5 and the positive lens 4, and the diffractive structure have
characteristics in which the back focus becomes short on the
long wavelength side, the axial chromatic aberration
generated in the objective lens 3 is corrected. Further, in

the present example, fN =-5.54 (mm), fP = 7.42 (mm), and f1 = 1.765 (mm).

Because the correction of the variation of the spherical aberration at the time of the wavelength variation of the light source or temperature change in the present example is the same as in the example 1, the explanation is neglected. As can clearly be seen from Table 16, the spherical aberration at the time of the wavelength variation or temperature change becomes fine. Further, when the plastic material is used for the objective lens 3, negative lens 5 and positive lens 4, the weight reduction of the optical system and the reduction of the burden onto the movable mechanism are intended.

Table 16

Example 8

Image height characteristic WFE rms		Y = 0 μm Y = 10 μm	0.009λ (1.00 mm) 0.017λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm Δf_B (μm)	0.008λ (0.95 mm) +0.83
	- 10 nm	Y = 0 μm Δf_B (μm)	0.013λ (1.06 mm) -1.21
Temperature characteristic WFE rms	+ 30 °C - 30 °C	Y = 0 μm	0.007λ (0.92 mm) 0.022λ (1.08 mm)

Note) The figure in the parentheses in the Table expresses the interval between the negative lens and the positive lens of the spherical aberration correction means, and the divergent angle changing means.

[Example 9]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 9 is shown in Table 17.

Table 17

Example 9
λ1 405 nm
NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Spherical aberration correction means	-4.940	0.800	1.61949	30.0
2 (Aspheric surface 2)		5.707	1.000		
3 (Aspheric surface 3)		8.857	1.200	1.52524	56.5
4 (Aspheric surface 4, diffractive surface 1)		-5.570	1.000		
5 (Diaphragm)		∞	0.000		
6 (Aspheric surface 5)	Objective lens	1.225	2.845	1.52524	56.5
7 (Aspheric surface 6)		-0.763	0.292		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Aspheric surface 1
K   7.47423E-01
A_4 -1.05216E-03
A_6 1.83191E-03
A_8 -7.42838E-04
A_{10} -1.82340E-03

Aspheric surface 2
K   2.05271E-01
A_4 2.17539E-04
A_6 -1.28316E-03
A_8 -8.89776E-04
A_{10} -4.69136E-04

Aspheric surface 3
K   1.16167E+00
A_4 2.41421E-04
A_6 -1.36517E-05
A_8 5.39496E-05
A_{10} 3.14626E-05
A_{12} -4.79376E-05

Aspheric surface 4
K   1.25410E-01
A_4 -1.41630E-04
A_6 1.31960E-04
A_8 7.62960E-05
A_{10} -3.79170E-06
A_{12} -2.37460E-05

Aspheric surface 5
K   -6.99712E-01
A_4 1.66009E-02
A_6 2.09051E-03
A_8 1.57932E-03
A_{10} 2.12509E-04
A_{12} -3.44184E-04
A_{14} 1.19417E-05
A_{16} 5.77745E-05
A_{18} 4.09189E-05
A_{20} -2.57292E-05

Aspheric surface 6
K   -2.00337E+01
A_4 3.31327E-01
A_6 -8.81378E-01
A_8 9.65015E-01
A_{10} -4.12771E-01
A_{12} -2.52257E-04
A_{14} -1.10756E-10
A_{16} -1.68921E-11
A_{18} -2.53030E-12
A_{20} -3.70376E-13

Diffractive surface 1
b_2 -1.00000E-02
b_4 -5.64880E-05
b_6 6.33930E-05
b_8 6.62150E-05
b_{10} -4.80270E-06

Fig. 22 is an optical system structural view of the
negative lens 5, positive lens 4, and objective lens 3
according to the example 9. Fig. 23 is a spherical
aberration view according to the objective lens 3. In the
example 9, the information is recorded or reproduced by the

combination of the first light source 11 of the wavelength

405 nm and the image side numerical aperture NA 0.85 of the

objective lens 3. In the example 9, when the diffractive

surface is added to the surface of the optical information

recording medium side of the positive lens 4, and the

diffractive structure has characteristics in which the back

focus becomes short on the long wavelength side, the axial

chromatic aberration generated in the objective lens 3 is

corrected. Further, as the material of the negative lens 5

and the positive lens 4 of the spherical aberration

correction means, by respectively selecting the materials of

N = 30.0 and P =56.5, the axial chromatic aberration in the

objective lens 3 is more finely corrected. Further, in the

present example, fN =-4.15 (mm), fP = 5.91 (mm), and f1 =

1.765 (mm).

Because the correction of the variation of the

spherical aberration at the time of the wavelength variation

of the light source or temperature change in the present

example is the same as in the example 1, the explanation is

neglected. As can clearly be seen from Table 18, the

spherical aberration at the time of the wavelength variation

or temperature change becomes fine. Further, when the

plastic material is used for the objective lens 3, negative

lens 5 and positive lens 4, the weight reduction of the

optical system and the reduction of the burden onto the

movable mechanism are intended.

Table 18

Example 9

Image height characteristic WFE rms		Y = 0 μm Y = 10 μm	0.006λ (1.00 mm) 0.016λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm Δf_B (μm)	0.006λ (0.95 mm) +0.65
	− 10 nm	Y = 0 μm Δf_B (μm)	0.007λ (1.05 mm) −0.95
Temperature characteristic WFE rms	+ 30 °C − 30 °C	Y = 0 μm	0.005λ (0.95 mm) 0.012λ (1.05 mm)

Note) The figure in the parentheses in the Table expresses

the interval between the negative lens and the positive lens

of the spherical aberration correction means, and the

divergent angle changing means.

[Example 10]

The data relating to the optical system composed of the

negative lens 5, positive lens 4 and objective lens 3 in the

example 10 is shown in Table 19.

Table 19

Example 10
λ1 405 nm
NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Spherical aberration correction means	-17.882	0.800	1.66845	24.3
2 (Aspheric surface 2)		7.461	1.500		
3 (Diffractive surface 1)		7.218	1.200	1.52491	56.5
4 (Diffractive surface 2)		∞	2.500		
5 (Diaphragm)		∞	-1.000		
6 (Aspheric surface 3)	Objective lens	1.194	2.650	1.52491	56.5
7 (Aspheric surface 4)		-0.975	0.355		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Aspheric surface coefficient
Aspheric surface 1
K -180.985319
A_4 0.213341E-02
A_6 -0.309153E-03
A_8 -0.923446E-03
A_{10} 0.434595E-03
Aspheric surface 2

K 6.460482
A_4 0.303589E-02
A_6 -0.127523E-02
A_8 -0.661011E-03
A_{10} 0.354629E-03
Aspheric surface 3

K -0.683354
A_4 0.162029E-01
A_6 0.154908E-02
A_8 0.289288E-02
A_{10} -0.367711E-03
A_{12} -0.358222E-03
A_{14} 0.148419E-03
A_{16} 0.119603E-03
A_{18} -0.302302E-04
A_{20} -0.110520E-04

Aspheric surface 4

K   -21.704418
A_4 0.308021
A_6 -0.639499
A_8 0.585364
A_{10} -0.215623
A_{12} -0.252265E-03
Diffractive surface coefficient

Diffractive surface 1
b_2 -6.7880E-03
b_4 -1.2066E-04
Diffractive surface 2

b_2 -9.7794E-03
b_4 5.1838E-04

Fig. 24 is an optical system structural view of the

negative lens 5, positive lens 4, and objective lens 3

according to the example 10. Fig. 25 is a spherical

aberration view according to the objective lens 3. In the

example 10, the information is recorded or reproduced by the

combination of the first light source 11 of the wavelength

405 nm and the image side numerical aperture NA 0.85 of the

objective lens 3. In the example 10, when the diffractive

surfaces are added to the both surfaces of the positive lens

4, and the diffractive structure has characteristics in which

the back focus becomes short on the long wavelength side, the

axial chromatic aberration generated in the objective lens 3

is corrected. In this case, when the axial chromatic

aberration of the composite system in which the objective

lens 3, and the negative lens 5 and the positive lens 4 as

the spherical aberration correction means are combined, is
made in the overcorrected condition, as shown in Fig. 25, a
spherical aberration curve of the oscillation wavelength (405
nm) of the first light source 11 and a spherical aberration
curve on the long and short wavelength are made to cross each
other. Thereby, when the mode hopping of the light source
occurs, deterioration of the wave front aberration at the
time of high frequency superimposition is very small, and for
example, even when the oscillation wavelength of the light
source is minutely varied, the shift of the position of the
best image plane can be suppressed to small. Further, when
the negative lens 5 which is the movable element as the
spherical aberration correction means, is formed into the
both side aspheric surface lens, the deterioration of the
wave front aberration at the time of the decentering of the
negative lens 5 or the tracking error is suppressed to small.
Further, as the material of the negative lens 5 and the
positive lens 4, by respectively selecting the materials of
vdN = 24.3 and vdP =56.5, the axial chromatic aberration in
the objective lens 3 is corrected, and the burden of the
diffractive structure added to the positive lens 4 is
lightened. Further, in the present example, fN =-7.78 (mm),
fP = 9.95 (mm), and f1 = 1.765 (mm).

In the present example, because the diaphragm to regulate the light flux is arranged on the optical information recording medium side from the top of the surface of the light source side of the objective lens 3, when the divergent light flux is incident, the light ray passing height of the surface on the most light source side of the objective lens 3 can be suppressed to small. This is preferable also for the size reduction or aberration correction of the objective lens 3.

Because the correction of the variation of the spherical aberration at the time of the wavelength variation of the light source or temperature change in the present example is the same as in the example 1, the explanation is neglected. As can clearly be seen from Table 20, the spherical aberration at the time of the wavelength variation or temperature change becomes fine. Further, when the plastic material is used for the objective lens 3, negative lens 5 and positive lens 4, the weight reduction of the optical system and the reduction of the burden onto the movable mechanism are intended. Further, because the plastic material whose internal transmitance is high for the short wavelength light, is used, the large amount of lenses can be produced at low cost, and the optical system having the high efficiency of utilization of light is realized. In this

connection, the movable mechanism is the transfer apparatus

of the negative lens 5 and the focusing mechanism of the

objective lens 3 in the example in the present specification.

Table 20

Example 10

Image height characteristic WFE rms		Y = 0 μm Y = 10 μm	0.004λ (1.50 mm) 0.011λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm Δf_B (μm)	0.004λ (1.29 mm) -0.94
	- 10 nm	Y = 0 μm Δf_B (μm)	0.010λ (1.72 mm) +0.82
Temperature characteristic WFE rms	+ 30 °C - 30 °C	Y = 0 μm	0.013λ (1.26 mm) 0.023λ (1.76 mm)

Note) The figure in the parentheses in the Table expresses

the interval between the negative lens and the positive lens

of the spherical aberration correction means, and the

divergent angle changing means.

In this connection, in the present example, although

not shown in Fig. 25, as shown in the embodiment in Fig. 1,

in the practical optical pick-up apparatus, a coupling lens

such as a collimator is provided between the light source and

the spherical aberration correction means. In this case,

also the axial chromatic aberration generated in the coupling

lens can be corrected by the structure of the present

example, and the converging optical system having the fine

chromatic aberration can be obtained.

Further, so-called 2 layer recording system optical information recording medium is well known in which, by providing two phase change layers for the first information recording layer and the second information recording layer on the one side of the optical information recording medium, and by recording the information on each of them, the storage capacity of the optical information recording medium is increased to about 2 times, however, the apparatus in the present example can also be applied for recording or reproducing of the information for such the 2 layer recording system optical information recording medium, and the spherical aberration generated by the difference in the thickness between the incident plane of the light flux and the information recording plane of each information recording layer can be corrected. For example, when, in the order from the incident plane of the light flux of the optical information recording medium, the first information recording layer and the second information recording layer are defined, as shown in Fig. 26, by reducing the interval between the negative lens 5 and the positive lens 4 as the spherical aberration correction means, the recording or reproducing of the information can conducted onto the information recording plane of the second information recording layer.

[Example 11]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 11 is shown in Table 21.

Table 21

Example 11
$\lambda 1$ 405 nm
NA 0.85

		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Spherical aberration correction means	-11.505	0.800	1.52491	56.5
2 (Aspheric surface 2)		7.202	3.000		
3		∞	1.200	1.52491	56.5
4		-6.458	3.000		
5 (Diaphragm)			0.000		
6 (Aspheric surface 3, diffractive surface 1)	Objective lens	1.258	2.620	1.52491	56.5
7 (Aspheric surface 4)		-1.023	0.330		
8	Transparent substrate	∞	0.100	1.61950	30.0
9		∞			

Aspheric surface coefficient
Aspheric surface 1
    $K=$ -47.861166
    $A_4=$ 0.401592 x 10^{-2}
    $A_6=$ 0.290627 x 10^{-2}
    $A_8=$ 0.694294 x 10^{-3}
    $A_{10}=$ -0.493101 x 10^{-2}

Aspheric surface 2
    $K=$ 11.392515
    $A_4=$ 0.273496 x 10^{-2}
    $A_6=$ 0.238867 x 10^{-2}
    $A_8=$ -0.86487 x 10^{-3}
    $A_{10}=$ -0.324593 x 10^{-2}

Aspheric surface 3

K=	-7.0631×10^{-1}
A_4=	1.8891×10^{-2}
A_6=	-1.2594×10^{-3}
A_8=	4.3129×10^{-3}
A_{10}=	-3.1523×10^{-4}
A_{12}=	-8.1023×10^{-4}
A_{14}=	6.1785×10^{-5}
A_{16}=	1.7038×10^{-4}
A_{18}=	-7.7915×10^{-6}
A_{20}=	-1.8397×10^{-5}

Aspheric surface 4

K=	-32.230932
A_4=	0.202088
A_6=	-0.395843
A_8=	0.286204
A_{10}=	-0.715179×10^{-1}
A_{12}=	-0.252269×10^{-3}

Diffractive surface coefficient
Diffractive surface 1

b_2	-1.7601×10^{-2}
b_4	-2.3203×10^{-3}
b_6	-2.1692×10^{-4}
b_8	-2.4765×10^{-5}
b_{10}	-9.4777×10^{-5}

Fig. 27 is an optical system structural view of the negative lens 5, positive lens 4, and objective lens 3 according to the example 11. Fig. 28 is a spherical aberration view according to the objective lens 3. In the example 11, the information is recorded or reproduced by the combination of the first light source 11 of the wavelength 405 nm and the image side numerical aperture NA 0.85 of the objective lens 3. In the example 11, when the diffractive surface is added to the surface of the light source side of the objective lens 3, and the diffractive structure has

characteristic in which the back focus becomes short on the
long wavelength side, the axial chromatic aberration
generated in the objective lens 3 is corrected. Further,
when the negative lens 5 which is a movable element as the
spherical aberration correction means, is the both side
aspheric lens, the deterioration of the wave front aberration
at the time of the decentering of the negative lens 5 or the
tracking error is suppressed to small. Further, in the
present example, $fN = -8.32$ (mm), $fP = 12.30$ (mm), and $f1 =$
1.765 (mm), and $fD = 28.417$ (mm).

Because the correction of the variation of the
spherical aberration at the time of the wavelength variation
of the light source or temperature change in the present
example is the same as in the example 1, the explanation is
neglected. As can clearly be seen from Table 22, the
spherical aberration at the time of the wavelength variation
or temperature change becomes fine. Further, when the
plastic material is used for the objective lens 3, negative
lens 5 and positive lens 4, the weight reduction of the
optical system and the reduction of the burden onto the
movable mechanism are attained. Further, because the plastic
material whose internal transmitance is high for the short
wavelength light, is used, the large amount of lenses can be

produced at low cost, and the optical system having the high efficiency of utilization of light is attained.

Table 22

Example 11

Image height characteristic WFE rms		Y = 0 μm Y = 10 μm	0.008λ (3.00 mm) 0.011λ
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm Δf_B (μm)	0.007λ (3.01 mm) +0.12
	− 10 nm	Y = 0 μm Δf_B (μm)	0.009λ (2.99 mm) −0.36
Temperature characteristic WFE rms	+ 30 °C − 30 °C	Y = 0 μm	0.016λ (2.80 mm) 0.029λ (3.21 mm)

Note) The figure in the parentheses in the Table expresses the interval between the negative lens and the positive lens of the spherical aberration correction means, and the divergent angle changing means.

[Example 12]

The data relating to the optical system composed of the negative lens 5, positive lens 4 and objective lens 3 in the example 12 is shown in Table 23.

Table 23

Example 12
λ1 405 nm   NA1 0.85
λ2 655 nm   NA2 0.65

Surface No.		r (mm)	d (mm)	$N_{\lambda 1}$	vd
1 (Aspheric surface 1)	Spherical aberration correction means	-14.461	1.000	1.52491	56.5
2 (Aspheric surface 2)		4.468	(variable interval 1)		
3 (Aspheric surface 3)		5.516	1.500	1.52491	56.5
4		∞	1.700		
5 (Diaphragm)			-0.700		
3 (Aspheric surface 4, diffractive surface 1)	Objective lens	1.203	2.497	1.52491	56.5
4 (Aspheric surface 5)		-1.207	(variable interval 2)		
5	Transparent substrate	∞	(variable interval 3)	1.61950	30.0
6		∞			

Aspheric surface coefficient
Aspheric surface 1
        K=   -303.128595
        A_4= 0.708268×10^{-2}
        A_6= -0.189289×10^{-1}
        A_8= 0.190213×10^{-1}
        A_{10}= -0.271581×10^{-2}

Aspheric surface 2
        K=   3.803233
        A_4= 0.588950×10^{-2}
        A_6= -0.167364×10^{-1}
        A_8= 0.113657×10^{-1}
        A_{10}= 0.615860×10^{-3}

Aspheric surface 3
$$K= \quad 1.637827$$
$$A_4= \quad -0.395830 \times 10^{-2}$$
$$A_6= \quad 0.115426 \times 10^{-2}$$
$$A_8= \quad -0.543755 \times 10^{-3}$$
$$A_{10}= \quad 0.885518 \times 10^{-4}$$

Aspheric surface 4
$$K= \quad -6.8335 \times 10^{-1}$$
$$A_4= \quad 1.6203 \times 10^{-2}$$
$$A_6= \quad 1.5491 \times 10^{-3}$$
$$A_8= \quad 2.8929 \times 10^{-3}$$
$$A_{10}= \quad -3.6771 \times 10^{-4}$$
$$A_{12}= \quad -3.5822 \times 10^{-4}$$
$$A_{14}= \quad 1.4842 \times 10^{-4}$$
$$A_{16}= \quad 1.1960 \times 10^{-4}$$
$$A_{18}= \quad -3.0230 \times 10^{-5}$$
$$A_{20}= \quad -1.1052 \times 10^{-5}$$

Aspheric surface 5
$$K= \quad -26.275787$$
$$A_4= \quad 0.291992$$
$$A_6= \quad -0.513328$$
$$A_8= \quad 0.415634$$
$$A_{10}= \quad -0.137436$$
$$A_{12}= \quad -0.252265 \times 10^{-3}$$

Diffractive surface coefficient
Diffractive surface 1
$$b_2 \quad -1.1002 \times 10^{-2}$$
$$b_4 \quad -1.9824 \times 10^{-3}$$
$$b_6 \quad 3.3680 \times 10^{-4}$$
$$b_8 \quad -9.6881 \times 10^{-5}$$
$$b_{10} \quad -4.2391 \times 10^{-4}$$
$$b_{12} \quad 2.2319 \times 10^{-4}$$
$$b_{14} \quad -2.3482 \times 10^{-5}$$
$$b_{16} \quad -9.2757 \times 10^{-6}$$

	$\lambda 1$	$\lambda 2$
(Variable interval 1)	4.000	0.335
(Variable interval 2)	0.377	0.200
(Variable interval 3)	0.100	0.600

Figs. 29 and 30 are optical system structural views of

the negative lens 5, positive lens 4, and objective lens 3

according to the example 12. Figs. 31 and 32 are spherical

aberration views according to the objective lens 3 when the

information is recorded or reproduced respectively for the

different optical information recording media. The example

12 is an example of the optical pick-up apparatus by which

the information is recorded or reproduced by the combination

of the first light source 11 of the wavelength 405 nm and the

optical information recording medium of the transparent

substrate thickness 0.1 mm, or by the combination of the

second light source 11 of the wavelength 655 nm and the

optical information recording medium of the transparent

substrate thickness 0.6 mm. In the example 12, when the

diffractive surface is added to the surface of the light

source side of the objective lens 3, the spherical aberration

and the spherical aberration of the color, generated by the

difference in the transparent substrate thickness, are

corrected. Specifically, it is conducted, by moving the

negative lens 5 as the spherical aberration correction means

in the optical axis direction, when the slope angle of the

marginal ray of the light flux incident to the objective lens

3 is changed corresponding to the transparent substrate

thickness of the information recording medium. Further, in

the present example, fN = -6.39 (mm), fP = 10.51 (mm), and f1 = 1.765 (mm), and fD1 = 45.46 (mm). In this connection, the focal length of the objective lens at the oscillation wavelength $\lambda 2$ = 655 nm is f2 = 1.79.

Because the correction of the variation of the spherical aberration at the time of the wavelength variation of the light source or temperature change in the present example is the same as in the example 1, the explanation is neglected. As can clearly be seen from Table 24, the spherical aberration at the time of the wavelength variation or temperature change becomes fine. Further, when the plastic material is used for the objective lens 3, negative lens 5 and positive lens 4, the weight reduction of the optical system and the reduction of the burden onto the movable mechanism are attained. Further, because the plastic material whose internal transmitance is high for the short wavelength light, is used, a large amount of lenses can be produced at low cost, and the optical system having the high efficiency of utilization of light is attained.

Table 24

Example 12

			405 nm NA 0.85	655 nm NA 0.65
Image height characteris tic WFE rms		Y = 0 μm Y = 10 μm	0.005λ (4.00 mm) 0.033λ	0.002λ (0.33 mm) 0.014
Wavelength characteris tic WFE rms	+ 10 nm	Y = 0 μm Δf_B (μm)	0.011λ (4.01 mm) +1.45	0.002λ (0.35 mm) -1.28
	- 10 nm	Y = 0 μm Δf_B (μm)	0.007λ (3.99 mm) -1.28	0.003λ (0.32 mm) +1.28
Temperature characteris tic WFE rms	+ 30 °C - 30 °C	Y = 0 μm	0.016λ (3.85 mm) 0.026λ (4.17 mm)	0.005 λ (0.33 mm) 0.004 λ (0.34 mm)

Note) The figure in the parentheses in the Table expresses

the interval between the negative lens and the positive lens

of the spherical aberration correction means, and the

divergent angle changing means.

In this connection, in the same manner as in the

examples 4 and 5, when the light flux more than NA 0.65 to

the optical information recording medium of the light source

wavelength 655 nm and the transparent substrate thickness 0.6

mm, is made a flare component by using the effect of the

diffractive surface provided on the objective lens 3, the

spot diameter is not excessively squeezed on the information

recording plane, and the detection of the unnecessary signal

on the light receiving element of the optical pick-up

apparatus can be prevented.

[Example 13]

The data relating to the optical system composed of a coupling lens 21, or collimator corresponding to the coupling lenses 15 and 21, the negative lens 5, positive lens 4 and objective lens 3 in the example 13 is shown in Table 25.

Table 25

Example 13
λ1 405 nm
NA 0.85

Surface No.		r (mm)	d (mm)	$N_{\lambda1}$	vd
	Light source		11.450		
1 (Aspheric surface 1)	Coupling lens	19.575	1.200	1.52491	56.5
2 (Aspheric surface 2)		-9.091	d2 (variable)		
3 (Aspheric surface 3)	Spherical aberration correction means	-7.656	0.800	1.52491	56.5
4 (Aspheric surface 4)		21.942	d4 (variable)		
5 (Diffractive surface 1)		∞	1.200	1.52491	56.5
6 (Diffractive surface 2)		-22.590	2.500		
7 (Diaphragm)		∞	0.000		
8 (Aspheric surface 5)	Objective lens	1.194	2.650	1.52491	56.5
9 (Aspheric surface 6)		-0.975	0.355		
10	Transparent substrate	∞	0.100	1.61949	30.0
11		∞	0.000		

Aspheric surface coefficient
Aspheric surface 1
K   117.804975
A_4 0.329240E-02
A_6 -0.182464E-02
A_8 0.140707E-02
A_{10} -0.640870E-03

Aspheric surface 2
K   -6.746762
A_4 0.111141E-02
A_6 0.282880E-02
A_8 -0.449522E-03
A_{10} -0.118579E-03

Aspheric surface 3
K   -19.770711
A_4 -0.749547E-03
A_6 0.187767E-02
A_8 0.123312E-03
A_{10} 0.333580E-03

Aspheric surface 4
K   105.955239
A_4 0.446828E-02
A_6 -0.226237E-02
A_8 0.112349E-02
A_{10} 0.112686E-03

Aspheric surface 5
K   -0.683354
A_4 0.162029E-01
A_6 0.154908E-02
A_8 0.289288E-02
A_{10} -0.367711E-03
A_{12} -0.358222E-03
A_{14} 0.148419E-03
A_{16} 0.119603E-03
A_{18} -0.302302E-04
A_{20} -0.110520E-04

Aspheric surface 6
K   -21.704418
A_4 0.308021
A_6 -0.639499
A_8 0.585364
A_{10} -0.215623
A_{12} -0.252265E-03

Diffractive surface coefficient
Diffractive surface 1
b_2 -1.0609E-02
b_4 -6.4692E-04

Diffractive surface 2
b_2 -1.6184E-02
b_4 5.9162E-04

Fig. 33 is an optical system structural view of the

collimator, negative lens 5, positive lens 4, and objective

lens 3 according to the example 13. Fig. 34 is a spherical

aberration view according to the objective lens 3. In the

example 13, the information is recorded or reproduced by the

combination of the first light source 11 of the wavelength

405 nm and the image side numerical aperture NA 0.85 of the

objective lens 3. In the example 13, by moving the negative

lens 5 in the spherical aberration correction means along the

optical axis direction, the slope angle of the marginal ray

of the light flux incident to the objective lens 3 is

changed, and the variation of the spherical aberration

generated on each optical surface of the converging optical

system (collimator and the objective lens 3) is corrected.

Further, in the present example, fN = -10.71 (mm), fP = 13.18

(mm), and f1 = 1.765 (mm).

Further, diffractive surfaces are added to both

surfaces of the positive lens 4, and the axial chromatic

aberration having the inverse sign to that of the axial

chromatic aberration generated by the optical surface of the

converging optical system is generated in the spherical

aberration correction means itself, thereby, the axial

chromatic aberration generated by the optical surface of the

converging optical system is corrected, and the axial

chromatic aberration of the wave front when the focus is

formed on the information recording plane is made fine. In

the converging optical system in the present example, when

the axial chromatic aberration generated by the collimator

and the objective lens 3, are respectively $\Delta fB1$, and $\Delta fB2$,

and ratio of them is approximately found, because the focal

length of the collimator is 12 mm, the magnification of the

spherical aberration correction means is 1.23 times, and the

focal length of the objective lens is 1.765 mm, $\Delta fB1/\Delta fB2$ =

1/30. That is, when the absolute value of the axial

chromatic aberration, generated by the spherical aberration

correction means is made almost the same value as the

absolute value of the axial chromatic aberration generated by

the objective lens, the axial chromatic aberration of the

wave front when the focus is formed on the information

recording plane can be made fine. At the time, when the

axial chromatic aberration of the composite system in which

the converging optical system, and the negative lens 5 and

the positive lens 4 as the spherical aberration correction

means are combined, is corrected in the overcorrected

condition, as shown in Fig. 34, the spherical aberration

curve of the oscillation wavelength (405 nm) of the first

light source 11 and the spherical aberration curve of the

long · short wavelength side are crossed each other.

Thereby, even when the mode hop phenomenon of the light

source or the deterioration of the wave front aberration at

the time of the high frequency superimposition is very small,
for example, the oscillation wavelength of the light source
is minutely varied, the shift of the position of the best
image plane can be suppressed to small. Further, when the
negative lens 5 which is a movable element in the spherical
aberration correction means, is biaspherical surface lens,
the decentering of the negative lens 5 or deterioration of
the wave front aberration at the time of the tracking error
is suppressed to small.

As can clearly be seen from Table 26, the variation of
the spherical aberration generated on each optical surface of
the converging optical system due to various factors, such as
at the time of the wavelength variation or temperature
change, can be corrected, and the spherical aberration
becomes fine. Further, when the plastic material is used for
all of the collimator and objective lens 3, and the negative
lens 5 and positive lens 4, constituting the spherical
aberration correction means, the weight reduction of the
optical system and the reduction of the burden onto the
movable mechanism are attained. Further, because the plastic
material whose internal transmitance is high for the short
wavelength light, is used, a large amount of lenses can be
produced at low cost, and the optical system having the high
efficiency of utilization of light is attained.

Table 26

Example 13

Cause of variation of spherical aberration			Wave front aberration after correction	d2 (variable)	d4 (variable)
Reference condition (λ =405 nm, T =25 °C)		Y = 0 μm	0.005λ	3.000	1.500
		Y = 10 μm	0.011λ		
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm	0.005λ	3.326	1.164
		Δf_B (μm)	-0.90		
	- 10 nm	Y = 0 μm	0.009λ	2.623	1.877
		Δf_B (μm)	+0.66		
Temperature characteristic WFE rms	+ 30 °C	Y = 0 μm	0.007λ	3.363	1.137
	- 30 °C		0.019λ	2.587	1.913

Note) An amount of oscillation wavelength variation $\Delta\lambda$ =+ 0.05 nm/°C of the light source at the temperature change.

In this connection, in the present example, the negative lens 5 in the spherical aberration correction means is made transferable, however, the positive lens 4 may be made transferable, further, also when both lenses are made transferable, in the same manner, the variation of the spherical aberration of the converging optical system can be corrected. Further, in the present example, although the axial chromatic aberration of the converging optical system and the spherical aberration correction means is corrected by the diffractive structure provided on the positive lens 4 in the spherical aberration correction means, the diffractive structure may also be provided on the surface of the other

lens, or the optical element having the surface provided with

the diffractive structure may be separately added to the

other portion.

[Example 14]

The data relating to the optical system composed of a

coupling lens 15, negative lens 5, positive lens 4 and

objective lens 3 in the example 14 is shown in Table 27.

Table 27

Example 14
λ1 405 nm
NA 0.85

Surface No.		r (mm)	d (mm)	$N_{\lambda 1}$	vd
	Light source		9.300		
1	Coupling lens	∞	1.000	1.52491	56.5
2 (Aspheric surface 1)		-10.078	d2 (variable)		
3 (Aspheric surface 2)	Spherical aberration correction means	-7.701	0.800	1.52491	56.5
4		∞	d4 (variable)		
5 (Diffractive surface 1)		∞	1.200	1.52491	56.5
6 (Diffractive surface 2)		-15.928	2.500		
7 (Diaphragm)		∞	0.000		
8 (Aspheric surface 3)	Objective lens	1.194	2.650	1.52491	56.5
9 (Aspheric surface 4)		-0.975	0.355		
10	Transparent substrate	∞	0.100	1.61949	30.0
11		∞	0.000		

Aspheric surface coefficient
Aspheric surface 1
K   18.245912
A_4 -0.281317E-02
A_6 0.530301E-02
A_8 -0.297176E-02
A_{10} 0.962649E-03

Aspheric surface 2
K   -5.052328
A_4 -0.433879E-02
A_6 0.267506E-02
A_8 0.14128E-02
A_{10} 0.388234E-03

Aspheric surface 3
K   -0.683354
A_4 0.162029E-01
A_6 0.154908E-02
A_8 0.289288E-02
A_{10} -0.367711E-03
A_{12} -0.358222E-03
A_{14} 0.148419E-03
A_{16} 0.119603E-03
A_{18} -0.302302E-04
A_{20} -0.110520E-04

Aspheric surface 4
K   -21.704418
A_4 0.308021
A_6 -0.639499
A_8 0.585364
A_{10} -0.215623
A_{12} 0.252265E-03

Diffractive surface coefficient
Diffractive surface 1
b_2 -1.1850E-02
b_4 -3.7111E-04

Diffractive surface 2
b_2 -1.5129E-02
b_4 3.5690E-04

Fig. 35 is an optical system structural view of the coupling lens 15, negative lens 5, positive lens 4, and objective lens 3 according to the example 14. The coupling leans 15 has a function to convert the strong divergent light flux from the first light source 11 to the weak divergent light flux. Fig. 36 is a spherical aberration view according to the objective lens 3. In the example 14, the information is recorded or reproduced by the combination of the first light source 11 of the wavelength 405 nm and the image side

numerical aperture NA 0.85 of the objective lens 3. In the example 14, by moving the negative lens 5 in the spherical aberration correction means along the optical axis direction, the slope angle of the marginal ray of the light flux incident to the objective lens 3 is changed, and the variation of the spherical aberration generated on each optical surface of the converging optical system (coupling lens 15 and the objective lens 3) is corrected. Further, in the present example, fN = -14.67 (mm), fP = 11.66 (mm), and f1 = 1.765 (mm).

Further, diffractive surfaces are added to both surfaces of the positive lens 4, and the axial chromatic aberration having the inverse sign to that of the axial chromatic aberration generated by the optical surface of the converging optical system is generated by the spherical aberration correction means itself, thereby, the axial chromatic aberration generated by the optical surface of the converging optical system is corrected, and the axial chromatic aberration of the wave front when the focus is formed on the information recording plane is made fine. At the time, when the axial chromatic aberration of the composite system in which the converging optical system, and the negative lens 5 and the positive lens 4 as the spherical aberration correction means are combined, is corrected in the

overcorrected condition, as shown in Fig. 36, the spherical

aberration curve of the oscillation wavelength (405 nm) of

the first light source 11 and the spherical aberration curve

of the long · short wavelength side are crossed each other.

Thereby, even when the mode hop phenomenon of the light

source or the deterioration of the wave front aberration at

the time of the high frequency superimposition is very small,

for example, the oscillation wavelength of the light source

is minutely varied, the shift of the position of the best

image plane can be suppressed to small.

As can clearly be seen from Table 28, the variation of

the spherical aberration generated on each optical surface of

the converging optical system due to various factors, such as

at the time of the wavelength variation or temperature

change, can be corrected, and the spherical aberration

becomes fine. Further, when the plastic material is used for

all of the coupling lens 15 and objective lens 3, and the

negative lens 5 and positive lens 4, constituting the

spherical aberration correction means, the weight reduction

of the optical system and the reduction of the burden onto

the movable mechanism are attained. Further, because the

plastic material whose permeability is high for the short

wavelength light, is used, a large amount of lenses can be

produced at low cost, and the optical system having the high

efficiency of utilization is attained. Further, in the
present example, because the incident light to the spherical
aberration correction means is a weak divergent light flux,
the power of the coupling lens 15 and the power of the
negative lens 5 in the spherical aberration correction means
may be small, and the deterioration of the wave front
aberration due to the eccentricity of respective lenses can
be suppressed to small.

Table 28

Example 14

Cause of variation of spherical aberration			Wave front aberration after correction	d2 (variable)	d4 (variable)
Reference condition (λ =405 nm, T =25 °C)		Y = 0 μm	0.004λ	3.000	1.500
		Y = 10 μm	0.012λ		
Wavelength characteristic WFE rms	+ 10 nm	Y = 0 μm	0.003λ	3.308	1.192
		Δf_B (μm)	-0.91		
	- 10 nm	Y = 0 μm	0.007λ	2.658	1.842
		Δf_B (μm)	+0.75		
Temperature characteristic WFE rms	+ 30 °C	Y = 0 μm	0.008λ	3.338	1.162
	- 30 °C		0.016λ	2.622	1.878

Note) An amount of oscillation wavelength variation $\Delta\lambda$ =+
0.05 nm/°C of the light source at the temperature change.

In this connection, in the present example, the
negative lens 5 in the spherical aberration correction means
is made transferable, however, the positive lens 4 may be
made transferable, further, also when both lenses are made

transferable, in the same manner, the variation of the spherical aberration of the converging optical system can be corrected. Further, in the present example, although the axial chromatic aberration of the converging optical system and the spherical aberration correction means is corrected by the diffractive structure provided on the positive lens 4 in the spherical aberration correction means, the diffractive structure may also be provided on the surface of the other lens, or other than this, the optical element having the surface provided with the diffractive structure may be separately added to the system.

In each of examples described above, as the spherical aberration correction means, the beam expander is used, and as the beam expander, although an example in which it is structured by a transferable negative single lens and a positive single lens, is shown, of course, the expander is not limited to that, but it may be a structure composed of 2 lens group or more lens groups, composed of a plurality of lenses, and so long as it does not depart from the sprit of the present invention, various modifications are possible.

Fig. 37 is a view showing the optical system according to the different embodiment. An element SE for correcting the variation of the spherical aberration is inserted. Such

the optical system can be used by replacing the negative lens 5, positive lens 4, and the objective lens 3 in Fig. 1.

The element SE is structured such that the X direction liquid crystal element SE1, 1/2 wavelength plate SE2, and Y direction liquid crystal element SE3 are respectively sandwiched among 4 glass plates SE4 from the coupling lens CL side. By electrically driving both liquid crystal elements SE1 and SE2, the variation of the spherical aberration can be corrected. Further, when the ring-shaped diffractive structure (not shown) is provided on the surface of the objective lens in the coupling lens CL, the chromatic aberration of the opposite phase to the axial chromatic aberration generated in the objective lens OL, that is, the axial chromatic aberration which is excessively corrected (over)on the short wavelength side, and the axial chromatic aberration which is insufficiently corrected (under) on the long wavelength side, can be generated. As the result, because the axial chromatic aberration is canceled, the wave front when the focus is formed on the optical information recording medium (not shown) through the element SE for correcting the variation of the spherical aberration and the objective lens OL, becomes the condition in which the axial chromatic aberration is suppressed to small.

Fig. 38 is a view showing the optical system according to the modification of the present embodiment. In Fig. 38, because the objective lens OL and the element SE for correcting the variation of the spherical aberration are the same as in the embodiment shown in Fig. 37, the explanation is omitted. In Fig. 38, the coupling lens CL has the composition in which the negative lens CL1 and the positive lens CL2 are cemented together, and Abbe's number vdN of the negative lens CL1 and Abbe's number vdP of the positive lens CL2 have the relationship of $vdN < vdP$.

As described above, when Abbe's numbers of the negative lens CL1 and the positive lens CL2 are selected appropriately, the coupling lens CL generates the axial chromatic aberration having the opposite sign to that of the axial chromatic aberration generated by the objective lens OL, that is, the overcorrected axial chromatic aberration as the wavelength decreases, and the undercorrected axial chromatic aberration as the wavelength increases, can be generated.

As the result, because the axial chromatic aberration is canceled, the wave front when the focus is formed on the optical information recording medium (not shown) through the coupling lens CL1 the element SE for correcting the variation

of the spherical aberration and the objective lens OL,
becomes the condition in which the axial chromatic aberration
is suppressed to small.

Fig. 39 is a sectional view (a) typically showing an
objective lens 3' applicable for the optical pick-up
apparatus of the present embodiment, and a front view (b)
viewed from the light source side. (Dashed line shows the
optical axis.)

This objective lens 3' can conduct the correction of
the spherical aberration deviation due to the difference of
the transparent substrate thickness of different optical
information recording media. In Fig. 36, the refractive
surface S1 on the light source side and the refractive
surface S2 on the optical disk side are both convex lenses
having the positive refracting power, which are aspherically
shaped. Further, the refractive surface S1 on the light
source side of the objective lens is structured by 4 divided
surfaces b1 to b4, coaxially with the optical axis. The
borders of the divided surfaces are provided with steps, and
respective divided surfaces are formed. According to that,
the spherical aberration and the wave front aberration of the
objective lens generate steps at portions corresponding to
the border portions.

In the ordinary objective lens, the generation of the
spherical aberration due to the difference in the transparent
substrate thickness of different information recording media
can not be avoided. However, the objective lens 3' used in
the present embodiment can not perfectly correct the
spherical aberration, however, as will be described below, it
is designed so that such the aberration is more softened.

Initially, when the information is reproduced and/or
recorded for the first optical information recording medium,
the refractive surface S1 and the refractive surface S2 are
designed so that the spherical aberration component of the
wave front aberration is within 0.05 $\lambda 1$ rms at the best image
surface position. The refractive surface S1 designed
according to this is applied for the first divided surface b1
and the fourth divided surface b4. Then, the new refractive
surface S1' is designed without using the refractive surface
S2 as a variable, so that the spherical aberration component
of the wave front aberration is within 0.05 $\lambda 2$ rms at the
best image surface position in the transparent substrate
thickness t3 (t1 $\leqq$ t3 $\leqq$ t2).

This refractive surface S1' is made the second divided
surface b2 and the third divided surface b3, and because the
transparent substrate thickness is optimized by the

transparent substrate thickness t3, at the time of the use of

the first optical disk 10, the best image surface position is

apparently formed at the position different from the best

image surface position formed by the first divided surface b1

and the fourth divided surface b4. However, the wave front

aberration is the aberration in which the inclination of the

wave front aberration in the divided surface is changed and

for example, in the first optical information recording

medium (for example, the next generation optical disk with

the higher density and capacity than the DVD), the wave front

aberration is right-downward, and in the second optical

information recording medium (for example, DVD), reversely,

it is a little right-upward. When such the divided surfaces

are partly provided more than 2 on the refractive surface S1,

the compatibility of the wave front aberrations in the

different optical information recording media becomes easy.

When the border position of each divided surface or the

axial thickness of the divided surface is appropriately

designed, the wave front aberration correction becomes

possible respectively at the beam spot minimum blur-circle

position in the next generation optical disk with the higher

density and capacity than the DVD, and in the DVD, at the

front focusing position. That is, in the next generation

optical disk with the higher density and capacity than the

DVD, the light is converged at the beam spot minimum blur-circle position by the objective lens, and the ray of light in the first to fourth light flux LB1 to LB4 has the spherical aberration of about several times of the wavelength $\lambda 1$, that is, $mi\lambda 1$ (mi is integer and i = 1, 2, …, k), at the beam spot minimum blur-circle position.

Further, because, in the DVD, the necessary numerical aperture NA2 is smaller than NA1, all of the first to fourth light fluxes LB1 to LB4 may not be effectively used, and in the optical pick-up apparatus of the present embodiment, the rays of light in the first to third light fluxes LB1 to LB3 have almost integer times of the wavelength $\lambda 2$, $ni\lambda 2$ (ni is integer and i = 1, 2, … , k). The fourth light flux LB4 is the unnecessary light in the case of the DVD, and is emitted as a flare at the position separated from the main spot light on the recording surface of the optical disk. Because this flare is vary small to the main spot light, when the diaphragm 8 is only remained as the equivalent to the necessary numerical aperture for the next generation optical disk with the higher density and capacity than the DVD, the reproduction of the DVD can be conducted without requiring the means for changing the numerical aperture of the diaphragm 8. Of course, at the time of the use of DVD, the

diaphragm 8 having the function to shield the fourth light flux LB4 may be used.

Accordingly, although the optical pick-up apparatus of the present example is provided with 4 divided surfaces b1 to b4, different from the objective lens of the related art, because it does not have a plurality of focal positions on each disk, the loss of the spot light amount can be reduced. Then, at the time of the use of each optical disk, the wave front aberration of the ray of light in the necessary numerical aperture is made almost integer times of the wavelength, and because the light fluxes passing through the necessary numerical aperture interfere with each other and enhance each other, the central intensity of the spot light is enhanced, and as the result, the sufficient reflection light amount from the optical disk is obtained, and as the interchangeable optical pick-up apparatus, the stable operation becomes possible.

In this connection, in the present example, 4 divided surfaces are provided on the objective lens, however, an objective lens with the surface having 3 portions to divide the incident light flux into practically 3 light fluxes, so as to be basically 3 divided surfaces, can also be used for the objective lens of the present invention. For example, it is a well known objective lens structured such that it has,

on at least one surface, at least the first portion, the
second portion and the third portion which divide the light
flux emitted from the light source into a plurality of light
fluxes by the refractive action in the order from the optical
axis side toward its outer periphery, wherein the first
portion and the third portion can converge the light flux
from the light source onto the information recording plane so
that these can record or reproduce the information for the
information recording plane of the first optical information
recording medium of the transparent substrate thickness t1,
and further, the first portion and the second portion can
converge the light flux from the light source onto the
information recording plane so that these can record or
reproduce the information for the information recording plane
of the second optical information recording medium of the
transparent substrate thickness t2 (t1 < t2).

According to the present embodiment, an optical pick-up
apparatus and optical system which can effectively correct
the axial chromatic aberration due to the mode hopping of the
semiconductor laser, an optical pick-up apparatus and optical
system which can effectively correct the variation of the
spherical aberration of the converging optical system due to
the temperature and humidity change, and an optical pick-up
apparatus which is provided with the short wavelength laser

and the high NA objective lens, and which can record or reproduce the information for the different kind of optical information recording media, can be provided. In this connection, of course, the present invention is not limited to the above embodiments or various examples.

A preferred embodiment of the invention will be explained as follows, referring to drawings. Fig. 40 is a schematic structure diagram of an optical pick-up apparatus pertaining to Embodiment 15.

The optical pick-up apparatus in Fig. 40 is equipped with semiconductor laser 3 representing a light source, coupling lens 2 (composed of two lens groups, namely of lens elements 2a and 2b wherein lens element 2a has positive refractive power, while lens element 2b has negative efractive power, and this applies also to the following embodiment) that changes a divergence angle of a divergent light emitted from light source 3, objective lens 1 that converges a light flux coming from coupling lens 2 on information recording plane 5 of an optical information recording medium, and detector 4 that receives reflected light from the information recording plane 5 of the optical information recording medium. The coupling lens 2 and the objective lens 1 constitute a converging optical system.

The optical pick-up apparatus in Fig. 40 is further equipped with beam splitter 6 that separates reflected light coming from information recording plane 5 toward detector 4, 1/4 wavelength plate 7 provided between coupling lens 2 and objective lens 1, diaphragm 8 provided to be ahead of objective lens 8, cylindrical lens 9, and actuator for focus tracking (first driving device: this applies also to the following embodiment) 10.

Further, the objective lens 1 has on its outer circumference flange portion 1a having a plane extending in the direction perpendicular to an optical axis. This flange portion 1a makes it possible to mount the objective lens 1 accurately on the optical pick-up apparatus. Biaxial actuator 10 makes the objective lens 1 to be capable of moving in the direction of an optical axis for focusing, and of moving in the direction perpendicular to an optical axis for tracking.

Coupling lens 2 may also be a collimator lens that makes a divergent light flux which has entered to be a light flux that is almost in parallel with an optical axis. In the present embodiment, lens element 2a of the coupling lens 2 is made to be capable of moving in the direction of an optical axis by actuator (second driving device: this applies also to the following embodiment) 11, for the purpose of correcting

deviation of spherical aberration caused on each optical
surface of the optical pick-up apparatus by changes of
oscillation wavelength of semiconductor laser 3, changes of
temperature and humidity, and errors of a thickness of a
transparent substrate of an optical information recording
medium.

(Example)

Next, Example 15 of a converging optical system which
can be applied to the present embodiment will be explained as
follows. In the Example 15 and other examples, light source
wavelength of semiconductor laser 3 is made to be 405 nm, and
a numerical aperture of objective lens 1 is made to be 0.85.
With regard to an aspherical surface in Example 15, it is
expressed by the following expression (numeral 1) under the
condition that x axis represents the direction of an optical
axis, h represents a height in the direction perpendicular to
an optical axis and r represents a radius of curvature of a
plane, in which κ represents the constant of the cone and A_{2i}
represents the constant of the aspheric surface.

(Numeral 1)

$$X = \frac{h^2/r}{1+\sqrt{1-(1+\kappa)h^2/r^2}} + \sum_{i=2} A_{2i}h^{2i}$$

On the other hand, with respect to a diffractive
surface, it is expressed with a generating aspheric surface

showing a macroscopic shape where a diffraction relief is removed and with function of optical path difference Φb of the following expression (Numeral 2). The function of optical path difference Φb is to express an optical path difference added to a diffraction light of the standard wavelength by the diffractive surface, and every time a value of the function of optical path difference Φb is changed by $m\lambda$ (m is a diffraction order), a diffraction zone is provided. In the expression, h represents a difference from an optical axis, and b_{21} represents a coefficient of the function of optical path difference.

(Numeral 2)

$$\phi_b = \sum_{i=1} b_{2i} h^{2i}$$

Lens data of a converging optical system of Example 15 are shown in Table 29. Further, a schematic sectional view of a converging optical system of the present example is shown in Fig. 41, and a diagram of spherical aberration is shown in Fig. 42. In the present example, axial chromatic aberration caused on a converging optical system is corrected by operations of a diffractive structure provided on each of the first and third surfaces of coupling lens 2 having the structure of 2 elements in 2 groups. In addition, as shown

in Table 30, spherical aberration caused on a converging

optical system by wavelength deviation of laser light source

3, temperature changes and a thickness error of a transparent

substrate can be corrected by changing a distance between

lens elements 2a and 2b of coupling lens 2.

Table 29

Example 15
λ1 405 nm
NA 0.85

Surface No.		r (mm)	d (mm)	$N_{\lambda 1}$	vd
0	Light source		9.524		
1 (Aspheric surface 1)	Coupling lens	∞	1.200	1.52491	56.5
2 (Diffractive surface 1)		-41.291	d2 (variable)		
3 (Aspheric surface 2)		∞	1.200	1.52491	56.5
4 (Diffractive surface 2)		-40.155	d4 (variable)		
5	Diaphragm		0.000		
6 (Aspheric surface 3)	Objective lens	1.194	2.650	1.52491	56.5
7 (Aspheric surface 4)		-0.975	0.355		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Constant of the aspheric surface
Aspheric surface 1
K   -6.0700E+02
A_4 2.1101E-04
A_6 6.3636E-04
A_8 -1.5044E-04

Aspheric surface 2
K   -5.4018E+02
A_4 7.6477E-04
A_6 -6.5149E-05
A_8 4.6581E-05
A_{10} -4.8124E-06

Aspheric surface 3
K   -6.8335E-01
A_4 1.6203E-02
A_6 1.5491E-03
A_8 2.8929E-03
A_{10} -3.6771E-04
A_{12} -3.5822E-04
A_{14} 1.4842E-04
A_{16} 1.1960E-04
A_{18} -3.0230E-05
A_{20} -1.1052E-05

Aspheric surface 4
K   -2.1704E+01
A_4 3.0802E-01
A_6 -6.3950E-01
A_8 5.8536E-01
A_{10} -2.1562E-01
A_{12} -2.5227E-04

Constant of diffractive surface
Diffractive surface 1
b_2 -2.4126E-02
b_4 -8.7753E-04

Diffractive surface 2
b_2 -1.1228E-02
b_4 -8.6150E-04

Table 30

Example 15

Causes of deviation of spherical aberration		Wavefront aberration after correction	d2 (variable)	d4 (variable)
Standard state (λ=405nm, T=25C°, t=0.100mm)		0.004λ	4.000	6.000
Wavelength deviation of light source	$\Delta\lambda$=+10nm	0.005λ	2.545	7.455
	$\Delta\lambda$=-10nm	0.010λ	5.616	4.384
Temperature change	ΔT=+30C°	0.010λ	2.279	7.721
	ΔT=-30C°	0.018λ	6.064	3.906
Error of thickness of transparent substrate	Δt=+0.02mm	0.008λ	1.551	8.449
	Δt=-0.02mm	0.007λ	7.126	2.874

(Note) Amount of change in oscillation wavelength of light source in temperature change $\Delta\lambda$ = + 0.05 nm/C°

Incidentally, in the present specifications (including lens data in Table), an exponent of 10 (for example, 2.5 x 10^{-3}) is expressed by the use of E (for example, 2.5 x E - 3).

Next, a converging optical system of Second Example
which can be used for the optical pick-up apparatus in Fig.
40 will be explained. First, lens data of the converging
optical system in the present example are shown in Table 31.
Further, a schematic sectional view of the converging optical
system in the present example is shown in Fig. 43 and a
diagram of spherical aberration is shown in Fig. 44. In the
present example, axial chromatic aberration caused on the
converging optical system is corrected by operations of the
diffractive structure provided on each of the third surface
of coupling lens 2 of 2 elements in 2 groups and the first
surface of objective lens 1 of 1 element in 1 group.
Further, as shown in Table 32, spherical aberration caused on
the converging optical system by wavelength deviation of
laser light source 3, temperature changes and by an error of
a thickness of a transparent substrate can be corrected by
changing the distance between lens elements 2a and 2b of
coupling lens 2. When a divergent light flux enters
objective lens 1, a point on the surface of objective lens 1
on the light source side where a beam passes through is
higher compared with an occasion wherein a collimated light
flux passing through a diaphragm having the same diameter
enters. For controlling occurrence of flare component by
aspheric surface of a high order in that case, a diaphragm

for regulating a light flux is arranged to be away from the
top on the surface of objective lens 1 on the light source
side toward an optical information recording medium, in the
present example.

Table 31

Example 16

Surface No.		r (mm)	d (mm)	$N_{\lambda 1}$	vd
0	Light source		d0 (variable)		
1 (Aspheric surface 1)	Coupling lens	-18.828	0.800	1.52491	56.5
2 (Diffractive surface 1)		16.312	d2 (variable)		
3 (Aspheric surface 2)		69.930	1.200	1.52491	56.5
4 (Diffractive surface 2)		-11.046	6.000		
5	Diaphragm		-1.000		
6 (Aspheric surface 3)	Objective lens	1.247	2.750	1.52491	56.5
7 (Aspheric surface 4)		-0.861	0.330		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞	0.000		

Constant of the aspheric surface
Aspheric surface 1
K   8.8068E+00
A_4 1.3574E-03
A_6 -3.0031E-02
A_8 -4.1461E-04

Aspheric surface 2
K   -6.6272E+02
A_4 -2.0667E-03
A_6 -7.2622E-03
A_8 -7.6379E-03

Aspheric surface 3
K   -3.9217E+00
A_4 3.7182E-04
A_6 8.0750E-04
A_8 1.1443E-04
A_{10} 5.3543E-05

Aspheric surface 4
K   -7.0271E-01
A_4 2.0793E-02
A_6 -2.5985E-03
A_8 4.9919E-03
A_{10} -2.2786E-04
A_{12} -9.5332E-04
A_{14} 4.6404E-05
A_{16} 1.7553E-04
A_{18} 2.1430E-05
A_{20} -2.9990E-05

Aspheric surface 5
K   -2.7384E+01
A_4 1.3778E-01
A_6 -3.2821E-01
A_8 2.6291E-01
A_{10} -7.8115E-02
A_{12} -2.5227E-04

Constant of diffractive surface
Diffractive surface 1
b_2 -1.6978E-02
b_4 7.8786E-04
b_6 -9.5788E-04
b_8 -6.4481E-05
b_{10} 3.1466E-06

Diffractive surface 2
b_2 -4.9893E-03
b_4 -3.7597E-04

Table 32

Example 16

Causes of deviation of spherical aberration		Wavefront aberration after correction	d2 (variable)	d4 (variable)
Standard state (λ=405nm, T=25C°, t=0.100mm)		0.006λ	9.300	4.700
Wavelength deviation of light source	$\Delta\lambda$=+10nm	0.007λ	9.385	4.615
	$\Delta\lambda$=-10nm	0.008λ	9.187	4.813
Temperature change	ΔT=+30C°	0.018λ	9.508	4.492
	ΔT=-30C°	0.026λ	9.079	4.921
Error of thickness of transparent substrate	Δt=+0.02mm	0.016λ	9.818	4.182
	Δt=-0.02mm	0.019λ	8.673	5.327

(Note) Amount of change in oscillation wavelength of light source in temperature change $\Delta\lambda$ = + 0.05 nm/C°

Next, an optical pick-up apparatus relating to Embodiment 16 will be explained. An optical pick-up apparatus shown in Fig. 45 is provided with objective lens 1 of 2 elements in 2 groups wherein plastic lenses 1a and 1b are held solidly by holding member 1c, semiconductor laser 3 representing a light source, coupling lens 2 (composed of lens elements 2a and 2b) that changes a divergence angle of a divergent light emitted from the light source, and detector 4 which receives reflected light from information recording plane 5 of the optical information recording medium. The objective lens 1 converges a light flux coming from the

coupling lens 2 on information recording plane 5 of the optical information recording medium.

The optical pick-up apparatus shown in Fig. 405 is provided with beam splitter 6 that separates reflected light coming from information recording plane 5 toward detector 4, 1/4 wavelength plate 7 arranged between coupling lens 2 and objective lens 1, diaphragm 8 arranged to be ahead of objective lens 1, cylindrical lens 9 and biaxial actuator 10 for focus tracking.

Further, the objective lens 1 has, on the outer circumference of its holding member 1c, flange portion 1d having a plane extending in the direction perpendicular to an optical axis. This flange portion 1d makes it possible to mount the objective lens 1 accurately on the optical pick-up apparatus.

The coupling lens 2 may also be a collimator lens that makes an entering divergent light flux to be a light flux that is mostly in parallel with an optical axis. In this case, lens element 2a of the coupling lens 2 is made to be capable of moving in the direction of an optical axis, for the purpose of controlling deviation of spherical aberration caused on each optical surface of the optical pick-up apparatus by changes of oscillation wavelength of semiconductor laser 3, changes of temperature and humidity,

and errors of a thickness of a transparent substrate of an
optical information recording medium.

Next, Example 17 of a converging optical system which
can be used for the present embodiment will be explained.
First, lens data of the converging optical system in the
present example are shown in Table 33. Further, a schematic
sectional view of the converging optical system in the
present example is shown in Fig. 8. In the present example,
axial chromatic aberration caused on the converging optical
system is corrected by operations of the diffractive
structure provided on each of the first and third surfaces of
coupling lens 2 of a 2 elements in 2 groups. Further, as
shown in Table 34, spherical aberration caused on the
converging optical system by wavelength deviation of laser
light source 3, temperature changes and by an error of a
thickness of the transparent substrate can be corrected by
changing the distance between lens elements 2a and 2b of
coupling lens 2.

Table 33

Example 17

Surface No.		r (mm)	d (mm)	$N_{\lambda 1}$	vd
0	Light source		9.557		
1 (Aspheric surface 1)	Coupling lens	∞	1.000	1.52491	56.5
2 (Diffractive surface 1)		-17.290	d2 (variable)		
3 (Aspheric surface 2)		∞	1.000	1.52491	56.5
4 (Diffractive surface 2)		-23.158	d4 (variable)		
5	Diaphragm		0.000		
6 (Aspheric surface 3)	Objective lens	1.870	1.700	1.52491	56.5
7 (Aspheric surface 4)		21.104	0.600		
8 (Aspheric surface 5)		0.916	1.100		
9		∞	0.150		
10	Transparent substrate	∞	0.100	1.61949	30.0
11		∞	0.000		

Constant of the aspheric surface

Aspheric surface 1
K   -2.1849E+01
A_4 5.6259E-04
A_6 6.5164E-04
A_8 -9.6165E-05

Aspheric surface 2
K   -2.6544E+01
A_4 6.8751E-04
A_6 2.4489E-04
A_8 2.9894E-05

Aspheric surface 3
K   -1.1034E-01
A_4 -6.0609E-03
A_6 -1.2828E-03
A_8 -5.4230E-04
A_{10} -1.0053E-04
A_{12} -3.1022E-06
A_{14} 1.3974E-08
A_{16} -8.2488E-06

Aspheric surface 4
K   1.0547E+02
A_4 7.2959E-03
A_6 -1.8973E-03
A_8 4.8022E-04
A_{10} -2.1096E-03
A_{12} 6.0792E-04

Aspheric surface 5
K   -1.9362E-01
A_4 1.8873E-02
A_6 -1.7301E-02
A_8 1.1456E-01
A_{10} -1.4290E-01

Constant of diffractive surface
Diffractive surface 1
b_2 -9.5885E-03
b_4 -8.0888E-04
b_6 -1.1868E-04

Diffractive surface 2
b_2 -9.5292E-03
b_4 -4.2952E-04
b_6 -2.2554E-04

Table 34

Example 17

Causes of deviation of spherical aberration		Wavefront aberration after correction	d2 (variable)	d4 (variable)
Standard state (λ=405nm, T=25C°, t=0.100mm)		0.001λ	4.000	5.000
Wavelength deviation of light source	Δλ=+10nm	0.004λ	4.130	4.870
	Δλ=-10nm	0.005λ	3.886	5.114
Temperature change	ΔT=+30C°	0.006λ	4.785	4.215
	ΔT=-30C°	0.008λ	3.249	5.751
Error of thickness of transparent substrate	Δt=+0.02mm	0.007λ	1.928	7.072
	Δt=-0.02mm	0.009λ	6.424	2.576

(Note) Amount of change in oscillation wavelength of light source in temperature change $\Delta\lambda = +0.05$ nm/C°

Next, the converging optical system of Example 18 which can be used for the optical pick-up apparatus shown in Fig. 45 will be explained. First, lens data of the converging optical system in the present example are shown in Table 35. Further, a schematic sectional view of the converging optical system in the present example is shown in Fig. 48, and a diagram of spherical aberration is shown in Fig. 49. In the present example, axial chromatic aberration caused on the converging optical system is corrected by operations of the diffractive structure provided on each of the third surface of coupling lens 2 of a 2 elements in 2 groups and the first

surface of the objective lens of 1 element in 1 group.
Further, as shown in Table 36, spherical aberration caused on
the converging optical system by wavelength deviation of
laser light source 3, temperature changes and by an error of
a thickness of the transparent substrate can be corrected by
changing the distance between lens elements 2a and 2b of the
coupling lens.

Table 35

Example 18

Surface No.		r (mm)	d (mm)	$N_{\lambda 1}$	νd
0	Light source		d0 (variable)		
1 (Aspheric surface 1)		- 125.213	0.800	1.52491	56.5
2 (Aspheric surface 2)	Coupling lens	10.615	d2 (variable)		
3 (Diffractive surface 1)		∞	1.000	1.52491	56.5
4 (Aspheric surface 3)		-8.470	5.000		
5	Diaphragm		0.000		
6 (Aspheric surface 4, Diffractive surface 2)		1.944	1.700	1.52491	56.5
7 (Aspheric surface 5)	Objective lens	32.238	0.600		
8 (Aspheric surface 6)		0.959	1.100		
9		∞	0.150		
10	Transparent substrate	∞	0.100	1.61949	30.0
11		∞	0.000		

Constant of the aspheric surface

Aspheric surface 1
K   1.8394E+03
A_4 -4.6322E-03
A_6 -2.1863E-03
A_8 -3.0571E-02

Aspheric surface 2
K   -4.2244E+01
A_4 -2.1729E-04
A_6 -7.3557E-03
A_8 -1.4106E-02

Aspheric surface 3
K   3.7370E-01
A_4 -7.5808E-04
A_6 6.2516E-05
A_8 -1.3333E-05
A_{10} 5.5520E-06

Aspheric surface 4
K   -1.0167E-01
A_4 -6.3824E-03
A_6 -1.0712E-03
A_8 -3.8459E-04
A_{10} -8.7158E-05
A_{12} 2.9718E-06
A_{14} 8.3886E-06
A_{16} -4.1865E-06

Aspheric surface 5
K   -3.4728E+02
A_4 3.1109E-03
A_6 8.4223E-04
A_8 2.7940E-03
A_{10} -2.6177E-03
A_{12} 1.0154E-03

Aspheric surface 6
K   -2.9075E-01
A_4 2.0673E-02
A_6 -2.2747E-02
A_8 1.1245E-01
A_{10} -9.7095E-02

Constant of diffractive surface
Diffractive surface 1
b_2 -1.3723E-02
b_4 6.4381E-04

Diffractive surface 2
b_2 -6.3411E-03
b_4 -9.0875E-05

Table 36

Example 18

Causes of deviation of spherical aberration		Wavefront aberration after correction	d2 (variable)	d4 (variable)
Standard state (λ=405nm, T=25C°, t=0.100mm)		0.001λ	8.000	5.000
Wavelength deviation of light source	Δλ=+10nm	0.002λ	8.128	4.872
	Δλ=-10nm	0.001λ	7.873	5.127
Temperature change	ΔT=+30C°	0.004λ	7.837	5.163
	ΔT=-30C°	0.006λ	8.162	4.838
Error of thickness of transparent substrate	Δt=+0.02mm	0.003λ	8.579	4.421
	Δt=-0.02mm	0.006λ	7.357	5.643

(Note) Amount of change in oscillation wavelength of light source in temperature change Δλ = + 0.05 nm/C°

Next, the converging optical system of Example 19 which can be used for the optical pick-up apparatus in Fig. 40 will be explained. First, lens data of the converging optical system in the present example are shown in Table 37. Further, a schematic sectional view of the converging optical system in the present example is shown in Fig. 50 and a diagram of spherical aberration is shown in Fig. 51. In the present example, axial chromatic aberration caused on the converging optical system is corrected by operations of the diffractive structure provided on each of the third surface of coupling lens 2 of 2 elements in 2 groups and the first

surface of objective lens 1 of 1 element in 1 group.

Further, as shown in Table 38, recording and/or reproduction

of information for an optical information recording medium

for the so-called 3-layer recording system wherein a

transparent substrate and three information recording layers

are laminated on one side is made possible,

by changing the distance between lens elements 2a and 2b of

coupling lens 2. Further, in the same way as in Examples 1 -

4, spherical aberration that is caused on a converging

optical system by wavelength deviation of light source 3,

temperature changes and a thickness error of a transparent

substrate in the course of recording and/or reproduction of

information for each information recording medium can be

corrected.

Table 37

Example 19

Surface No.		r (mm)	d (mm)	$N_{\lambda 1}$	vd
0	Light source		d0 (variable)		
1 (Aspheric surface 1)	Coupling lens	-15.158	0.800	1.52491	56.5
2 (Aspheric surface 2)		15.692	d2 (variable)		
3 (Diffractive surface 1)		-32.332	1.200	1.52491	56.5
4 (Aspheric surface 3)		-7.369	6.150		
5	Diaphragm		-1.150		
6 (Aspheric surface 4, Diffractive surface 2)	Objective lens	1.247	2.750	1.52491	56.5
7 (Aspheric surface 5)		-0.861	d7 (variable)		
8	Transparent substrate	∞	d8 (variable)	1.61949	30.0
9		∞	0.000		

Constant of the aspheric surface

Aspheric surface 1
K   2.2997E+02
A_4 -1.2113E-03
A_6 -2.3094E-02
A_8 5.7097E-04

Aspheric surface 2
K   -7.1651E+02
A_4 -5.0140E-04
A_6 -1.5428E-02
A_8 -5.7871E-03

Aspheric surface 3
K   -5.7990E-01
A_4 5.3861E-05
A_6 8.2843E-04
A_8 1.2847E-04
A_{10} 2.2449E-05

Aspheric surface 4
K   -7.0271E-01
A_4 2.0793E-02
A_6 -2.5985E-03
A_8 4.9919E-03
A_{10} -2.2786E-04
A_{12} -9.5332E-04
A_{14} 4.6404E-05
A_{16} 1.7553E-04
A_{18} 2.1430E-05
A_{20} -2.9990E-05

Aspheric surface 5
K   -2.7384E+01
A_4 1.3778E-01
A_6 -3.2821E-01
A_8 2.6291E-01
A_{10} -7.8115E-02
A_{12} -2.5227E-04

Constant of diffractive surface
Diffractive surface 1
b_2 -1.6939E-02
b_4 6.4086E-04
b_6 -9.2105E-04
b_8 -4.4088E-05
b_{10} 4.2021E-06

Diffractive surface 2
b_2 -4.9893E-03
b_4 -3.7597E-04

Table 38

Example 19

	First information recording layer	Second information recording layer	Third information recording layer
d0 (variable)	9.300	10.398	11.228
d2 (variable)	4.700	3.602	2.772
d7 (variable)	0.330	0.317	0.301
d8 (variable)	0.100	0.150	0.200
Wavefront aberration	0.007λ	0.010λ	0.008λ

Though the optical information recording medium is made
to be that of a 3-layer recording system wherein a thickness
of a transparent substrate interposed between information
recording layers is 0.05 mm in the present example, the
converging optical system in the present example can also
work for recording and/or reproduction of information for the
optical information recording medium of a multi-layer
recording system other than the foregoing.

Next, the converging optical system of Example 20 which
can be used for the optical pick-up apparatus in Fig. 40 will
be explained. First, lens data of the converging optical
system in the present example are shown in Tables 39 and 40.
Further, a schematic sectional view of the converging optical
system in the present example is shown in Fig. 42 and a
diagram of spherical aberration is shown in Fig. 43. In the
present example, axial chromatic aberration caused on the
converging optical system is corrected by operations of the
diffractive structure provided on each of the third and
fourth surfaces of coupling lens 2 of 2 elements in 2 groups.
Further, as shown in Table 41, spherical aberration that is
caused on a converging optical system by wavelength deviation
of light source 3, temperature changes and by a thickness
error of a transparent substrate can be corrected by changing

the distance between lens elements 2a and 2b of coupling lens

2.

Table 39

Example 20

Surface No.		r (mm)	d (mm)	Nλ	vd
0	Light source		d0 (variable)		
1	Coupling lens	∞	1.000	1.52491	56.5
2		-6.056	d2 (variable)		
3		∞	1.000	1.52491	56.5
4		-19.860	5.000		
5	Diaphragm	∞	0.000		
6	Objective lens	1.194	2.650	1.52491	56.5
7		-0.975	0.355		
8	Transparent substrate	∞	0.100	1.61949	30.0
9		∞			

Table 40

Constant of the aspheric surface
Second surface   k   7.8224E-01
                  A_4 -6.5522E-04
                  A_6 7.6018E-05
                  A_8 1.4178E-04

Fourth surface   k   -7.6290E+01
                  A_4 1.1179E-03
                  A_6 5.9633E-04
                  A_8 1.5178E-04
                  A_{10} 5.6734E-05

Sixth surface   k   -6.8335E-01
                  A_4 1.6203E-02
                  A_6 1.5491E-03
                  A_8 2.8929E-03
                  A_{10} -3.6771E-04
                  A_{12} -3.5822E-04
                  A_{14} 1.4842E-04
                  A_{16} 1.1960E-04
                  A_{18} -3.0230E-05
                  A_{20} -1.1052E-05

Seventh surface   k   -2.1704E+01
                   A_4 3.0802E-01
                   A_6 -6.3950E-01
                   A_8 5.8536E-01
                   A_{10} -2.1562E-01
                   A_{12} -2.5227E-04

Constant of diffractive surface
Third surface b_2 -1.2117E-02
                   b_4 -5.5463E-04
                   b_6 -1.6754E-04
                   b_8 -8.4468E-05
                   b_{10} -3.4341E-06

Fourth surface b_2 -1.1967E-02
                   b_4 -3.3959E-04
                   b_6 -6.3935E-05
                   b_8 -6.8699E-05
                   b_{10} -1.6431E-05

Table 41

Example 20

Causes of deviation of spherical aberration		Wavefront aberration	d0 (variable)	d2 (variable)
Standard state (λ=405nm, T=25C°, t=0.1mm)		0.004	5.000	2.000
Wavelength deviation of light source	$\Delta\lambda$=+10nm	0.004	4.956	2.044
	$\Delta\lambda$=-10nm	0.006	5.049	1.951
Temperature change	ΔT=+30C°	0.011	4.906	2.094
	ΔT=-30C°	0.014	5.093	1.907
Error of thickness of transparent substrate	Δt=+0.02mm	0.004	4.794	2.206
	Δt=-0.02mm	0.005	5.205	1.795

(Note) Amount of change in oscillation wavelength of light source in temperature change $\Delta\lambda$ = + 0.05 nm/C°

Since the converging optical system in Examples 15 - 20 above is made of a material of plastic whose saturated water absorption rate is 0.01% or less and internal transmitance at thickness of 3 mm in wavelength area to be used is 90% or more, its image quality is affected less by water absorption, its efficiency of utilization of light is high, and it can be manufactured at low cost on a mass production basis. Further, by using plastic whose specific gravity is 2.0 or less, it is possible to make an overall converging optical system light, and thereby to lighten a load on a driving mechanism (actuator 10 or the like) for objective lens 1 and on a driving mechanism (actuator 11) for coupling lens 2, thus, high speed driving and downsizing of the driving mechanism are made possible.

Fig. 54 is a schematic structure diagram of an optical pick-up apparatus related to Embodiment 17. The optical pick-up apparatus in Fig. 54 is only different from the optical pick-up apparatus in Fig. 40 on the point that actuator 11 moves lens element 2b instead of lens element 2a of coupling lens 2 in the direction of an optical axis, therefore, explanation for points other than the foregoing will be omitted here.

Fig. 55 is a schematic structure diagram of an optical pick-up apparatus related to Embodiment 18. The optical

pick-up apparatus in Fig. 55 is only different from the

optical pick-up apparatus in Fig. 45 on the point that

actuator 11 moves lens element 2b instead of lens element 2a

of coupling lens 2 in the direction of an optical axis,

therefore, explanation for points other than the foregoing

will be omitted here. Incidentally, any one of converging

optical systems in Examples 15 - 20 can be applied to the

optical pick-up apparatuses in Figs. 54 and 55. Further, the

distance between lens elements 2a and 2b of coupling lens 2

may also be changed by moving both of them as a variation of

the optical pick-up apparatuses in Figs. 54 and 55.

Another example will further be explained as follows.

Fig. 62 is a diagram showing an optical pick-up

apparatus equipped with uniaxial actuator 11 for moving

coupling lens 2 in the direction of an optical axis. It is

possible to cancel deviation of spherical aberration caused

on an optical system by changing the slope angle of the

marginal ray of a light flux entering objective lens 1 by

moving the coupling lens in the direction of an optical axis

by an appropriate amount by the uniaxial actuator 11

representing a moving device. Further, when spherical

aberration is caused on an optical system, when oscillation

wavelength of semiconductor laser 3 representing a light

source is varied, or when temperature or humidity is changed,

or by an error of a protector layer thickness in an optical

information recording medium, it is possible to cancel

deviation of the spherical aberration caused on the optical

system by moving coupling lens 2 in the direction of an

optical axis by an appropriate amount by the uniaxial

actuator 11 and thereby by changing the slope angle of the

marginal ray of a light flux entering objective lens 1.

Examples wherein a pick-up in Fig. 62 is used are shown below

as Examples 21 - 25.

(Example 21)

Lens data and the constant of the aspheric surface are

shown in Table 42. Fig. 56 shows sectional views of a

coupling lens of 1 element in 1 group and an objective lens

in Example 21, and Fig. 57 shows a diagram of spherical

aberration.

Table 42

Example 21

Surface No.		r (mm)	d (mm)	Nλ	νd
Light source			d0 (variable)		
1	Coupling lens	-62.022	1.200	1.52491	56.5
2 (Aspheric surface 1, Diffractive surface 1)		-4.608	d2 (variable)		
Diaphragm		∞	0		
3 (Aspheric surface 2)	Objective lens	1.194	2.650	1.52491	56.5
4 (Aspheric surface 3)		-0.975	0.355		
5	Transparent substrate	∞	0.100	1.61950	30.0
6		∞			

Aspheric surface 1
  $K=$ -2.4335E-01
  $A_4=$ 2.7143E-03
  $A_6=$ -5.6745E-05
  $A_8=$ 7.0168E-05
  $A_{10}=$ -1.5659E-05

Aspheric surface 2
  $K=$ -0.683354
  $A_4=$ 0.162029E-01
  $A_6=$ 0.154908E-02
  $A_8=$ 0.289288E-02
  $A_{10}=$ -0.367711E-03
  $A_{12}=$ -0.358222E-03
  $A_{14}=$ 0.148419E-03
  $A_{16}=$ 0.119603E-03
  $A_{18}=$ -0.302302E-04
  $A_{20}=$ -0.110520E-04

Aspheric surface 3
  $K=$ -21.704418
  $A_4=$ 0.308021E+00
  $A_6=$ -0.639499E+00
  $A_8=$ 0.585364E+00
  $A_{10}=$ -0.215623E+00
  $A_{12}=$ -0.252265E-03

Diffractive surface 1
    b_2 -2.0000E-02
    b_4 -1.3821E-03

In the present Example 21, it is intended to make an
optical system to be light, and to lighten a burden for a
focusing mechanism or a coupling lens moving device, by using
a plastic material for an objective lens and a coupling lens.
These lenses can be manufactured at low cost on a mass
production basis. Further, an optical system corrected axial
chromatic aberration satisfactorily by a simple structure is
realized, by making a coupling lens to be represented by a
diffractive lens in a form of a single lens. Table 43 shows
results of correction made by moving a coupling lens for
spherical aberrations generated by various causes. As is
apparent from this Table 43, spherical aberration generated
by wavelength deviation of a laser, temperature changes and
by a thickness error of a transparent substrate can be
corrected satisfactorily in the optical system of the present
example.

Table 43

Causes of deviation of spherical aberration		WFE-rms after correction	d0 (mm)	d2 (mm)
Standard state (λc-405nm, Tc=25°C, tc=0.1mm)		0.007λ	6.000	5.000
Wavelength deviation of LD	Δλ=+10nm	0.008λ	5.941	5.059
	Δλ=-10nm	0.022λ	6.054	4.946
Temperature changes	ΔT=+30C°	0.011λ	5.927	5.073
	ΔT=-30C°	0.031λ	6.071	4.929
Transparent substrate thickness error	Δt=+0.02mm	0.004λ	5.853	5.147
	Δt=-0.02mm	0.015λ	6.152	4.848

(Example 22)

    Lens data and the constant of the aspheric surface are
shown in Table 44. Schematic sectional views of the coupling
lens of a 1-element structure of Example 22 and an objective
lens are shown in Fig. 58 and a diagram of spherical
aberration is shown in Fig. 59.

Table 44

Example 22

Surface No.		r (mm)	d (mm)	Nλ	νd
Light source			d0 (variable)		
1 (Aspheric surface 1, Diffractive surface 1)	Coupling lens	-226.959	1.200	1.52491	56.5
2 (Aspheric surface 2, Diffractive surface 2)		-6.733	d2 (variable)		
Diaphragm		∞	0		
3 (Aspheric surface 3)	Objective lens	1.194	2.650	1.52491	56.5
4 (Aspheric surface 4)		-0.975	0.355		
5	Transparent substrate	∞	0.100	1.61950	30.0
6		∞			

Aspheric surface 1
$K=$ 0.0
$A_4=$ 1.0245E-02
$A_6=$ 9.6650E-04
$A_8=$ -5.9104E-04
$A_{10}=$ 8.9735E-05

Aspheric surface 2
$K=$ -4.3181
$A_4=$ 1.5848E-03
$A_6=$ 8.6137E-04
$A_8=$ -2.0117E-04
$A_{10}=$ 1.3168E-05

Aspheric surface 3
$K=$ -0.683354
$A_4=$ 0.162029E-01
$A_6=$ 0.154908E-02
$A_8=$ 0.289288E-02
$A_{10}=$ -0.367711E-03
$A_{12}=$ -0.358222E-03
$A_{14}=$ 0.148419E-03
$A_{16}=$ 0.119603E-03
$A_{18}=$ -0.302302E-04
$A_{20}=$ -0.110520E-04

Aspheric surface 4
$K=$ -21.704418
$A_4=$ $0.308021E+00$
$A_6=$ $-0.639499E+00$
$A_8=$ $0.585364E+00$
$A_{10}=$ $-0.215623E+00$
$A_{12}=$ $-0.252265E-00$

Constant of diffractive surface
Diffractive surface 1
$b_2=$ $-2.2967E-02$
$b_4=$ $2.1037E-03$

Diffractive surface 2
$b_2=$ $-1.7113E-02$
$b_4=$ $8.2815E-04$

In the present Example 22, an optical system is

lightened, and a burden for the focusing mechanism or for the

coupling lens moving device is lightened, by using plastic

materials for an objective lens and a coupling lens. It is

further possible to manufacture them at low cost on a mass

production basis by using plastic materials. When recording

information on an optical information recording medium,

deterioration in wavefront aberration caused by mode hopping

is an unallowable problem. In the present optical system, a

spherical aberration curve for the standard wavelength and

spherical aberration curves for the short and long

wavelengths are made to cross each other, by using bi-

diffractive surface lens representing a single lens which is

overcorrected in terms of axial chromatic aberration. As a

result, the shift of the position of the best image plane

caused by a wavelength shift is controlled to be small,

resulting in prevention of deterioration of wavefront

aberration in the case of mode hopping. Table 45 shows the

results of correction made by moving a coupling lens, for the

spherical aberration caused by various causes. As is

apparent from Table 45, the optical system of the present

example makes it possible to correct satisfactorily spherical

aberration caused by deviation of laser wavelength,

temperature changes and an error of transparent substrate

thickness.

Table 45

Causes of deviation of spherical aberration		WFE-rms after correction	d0 (mm)	d2 (mm)
Standard state (λc-405nm, Tc=25°C, tc=0.1mm)		0.008λ	6.000	5.000
Wavelength deviation of LD	$\Delta\lambda$=+10nm	0.009λ	5.869	5.131
	$\Delta\lambda$=-10nm	0.010λ	6.141	4.859
Temperature changes	ΔT=+30C°	0.006λ	5.905	5.095
	ΔT=-30C°	0.025λ	6.101	4.899
Transparent substrate thickness error	Δt=+0.02mm	0.003λ	5.867	5.133
	Δt=-0.02mm	0.014λ	6.139	4.861

(Example 23)

Table 46 shows lens data and the constant of the

aspheric surface. Fig. 60 shows sectional views for the

coupling lens of 2 elements in 1 group in Example 23 and the

objective lens, and Fig. 61 shows a diagram of spherical

aberration.

Table 46

Example 23

Surface No.		r (mm)	d (mm)	Nλ	νd
Light source			d0 (variable)		
1		13.531	1.000	1.91409	23.8
2	Coupling lens	2.551	2.100	1.71548	53.2
3 (Aspheric surface 1)		-5.765	d3 (variable)		
Diaphragm		∞	0		
3 (Aspheric surface 2)	Objective lens	1.194	2.650	1.52491	56.5
4 (Aspheric surface 3)		-0.975	0.355		
6	Transparent substrate	∞	0.100	1.61950	30.0
7		∞			

Aspheric surface 1
$K=$ 0.699858
$A_4=$ -0.53797E-3
$A_6=$ -0.352488E-3
$A_8=$ 0.595790E-4
$A_{10}=$ -0.152115E-4

Aspheric surface 2
$K=$ -0.683354
$A_4=$ 0.162029E-01
$A_6=$ 0.154908E-02
$A_8=$ 0.289288E-02
$A_{10}=$ -0.367711E-03
$A_{12}=$ -0.358222E-03
$A_{14}=$ 0.148419E-03
$A_{16}=$ 0.119603E-03
$A_{18}=$ -0.302302E-04
$A_{20}=$ -0.110520E-04

Aspheric surface 3
$K=$ -21.704418
$A_4=$ 0.308021E+00
$A_6=$ -0.639499E+00
$A_8=$ 0.585364E+00
$A_{10}=$ -0.215623E+00
$A_{12}=$ -0.252265E-03

In the Example 23, an optical system is lightened and a burden for the focusing mechanism is lightened by using plastic materials for an objective lens. Further, a doublet lens of 2 elements in 1 group is used to correct satisfactorily axial chromatic aberration of the optical system. Further, by making the surface on the optical information recording medium side to be an aspheric surface, a numerical aperture of a coupling lens can be made large by an effect of correction for an aspheric surface, and thereby, a compact optical system whose total length is short is realized. Table 47 shows the results of correction made by moving a coupling lens, for the spherical aberration caused by various causes. As is apparent from Table 47, the optical system of the present example makes it possible to correct satisfactorily spherical aberration caused by deviation of laser wavelength, temperature changes and an error of transparent substrate thickness.

Table 47

Causes of deviation of spherical aberration		WFE-rms after correction	d0 (mm)	d2 (mm)
Standard state (λc-405nm, Tc=25°C, tc=0.1mm)		0.008λ	7.230	5.000
Wavelength deviation of LD	Δλ=+10nm	0.008λ	7.134	5.096
	Δλ=-10nm	0.019λ	7.330	4.900
Temperature changes	ΔT=+30C°	0.015λ	7.050	5.180
	ΔT=-30C°	0.027λ	7.415	4.815
Transparent substrate thickness error	Δt=+0.02mm	0.006λ	6.987	5.243
	Δt=-0.02mm	0.015λ	7.486	4.744

(Example 24)

This is an example wherein a diffractive surface is provided only on one side of a coupling lens which is a single lens.

Table 48

Surface No.		r (mm)	d (mm)	Nλ	νd
Light source			d0 (variable)		
1 (Diffractive surface 1)	Coupling lens	∞	1.200	1.52491	56.5
2 (Aspheric surface 1)		-16.084	d2 (variable)		
Diaphragm		∞	0		
3 (Aspheric surface 2)	Objective lens	1.194	2.650	1.52491	56.5
4 (Aspheric surface 3)		-0.975	0.355		
5	Transparent substrate	∞	0.100	1.61950	30.0
6		∞			

Aspheric surface 1
K=   17.997115
$A_4=$ 0.759036E-03
$A_6=$ 0.311883E-03
$A_8=$ -0.123894E-03
$A_{10}=$ 0.196179E-04

Aspheric surface 2
K=   -0.683354
$A_4=$ 0.162029E-01
$A_6=$ 0.154908E-02
$A_8=$ 0.289288E-02
$A_{10}=$ -0.367711E-03
$A_{12}=$ -0.358222E-03
$A_{14}=$ 0.148419E-03
$A_{16}=$ 0.119603E-03
$A_{18}=$ -0.302302E-04
$A_{20}=$ -0.110520E-04

Aspheric surface 3
K=   -21.704418
$A_4=$ 0.308021E+00
$A_6=$ -0.639499E+00
$A_8=$ 0.585364E+00
$A_{10}=$ -0.215623E+00
$A_{12}=$ -0.252265E-03

Diffractive surface 1
$b_2=$ -2.6023E-02
$b_4=$ -2.1722E-04

In the Example 24, plastic materials are used for an objective lens and a coupling lens. Thus, the shift of the position of the best image plane caused by a wavelength shift is controlled to be small, and deterioration of wavefront aberration in the case of mode hopping is prevented. Further, deterioration of wavefront aberration in the case of surface-decentering of a coupling lens is prevented by providing an aspherical surface only on one side of the coupling lens. In addition, deterioration of wavefront aberration in the case of tracking error and of the decentering of the coupling lens are prevented, by providing a diffractive surface on the surface of the coupling lens on the light source side and by providing on the surface thereof on the objective lens side an aspheric surface whose refractive power is reduced as a position for the refracting power becomes more distant from an optical axis. Table 49 shows the results of correction made by moving a coupling lens, for the spherical aberration caused by various causes. As is apparent from Table 49, spherical aberration caused by deviation of laser wavelength, temperature changes and an error of transparent substrate thickness can be corrected satisfactorily and axial chromatic aberration can also be corrected satisfactorily.

Table 49

Causes of deviation of spherical aberration		WFE-rms after correction	d0 (mm)	d2 (mm)
Standard state (λc-405nm, Tc=25°C, tc=0.1mm)		0.005λ	11.670	5.000
Wavelength deviation of LD	Δλ=+10nm	0.008λ	11.404	5.266
	Δλ=-10nm	0.009λ	11.960	4.710
Temperature changes	ΔT=+30C°	0.014λ	11.373	5.297
	ΔT=-30C°	0.018λ	11.995	4.676
Transparent substrate thickness error	Δt=+0.02mm	0.009λ	11.246	5.424
	Δt=-0.02mm	0.008λ	12.136	4.534

According to the present invention, in an optical pickup apparatus for conducting reproducing and/or recording information of the high density optical information recording medium, deviation of spherical aberration can be corrected efficiently.

The invention makes it possible to provide a converging optical system and an optical pick-up apparatus wherein deviation of spherical aberration caused on each optical surface of the optical pick-up apparatus by oscillation wavelength changes of a laser light source, changes in temperature and humidity and an error of a transparent substrate thickness of an optical information recording medium can be corrected effectively by a simple structure.

The invention further makes it possible to provide a converging optical system and an optical pick-up apparatus

wherein axial chromatic aberration caused on an objective lens by mode hopping of a laser light source can be effectively corrected.

In addition, the invention makes it possible to provide a converging optical system and an optical pick-up apparatus wherein a short wavelength laser light source and an objective lens having a high numerical aperture are provided, and recording and/or reproduction of information for a plurality of information recording media each having a transparent substrate with a different thickness can be conducted.

With regard to an objective lens for the optical pick-up apparatus, the invention makes it possible to provide an aspherical objective lens that is a single lens having a large numerical aperture and excellent image height characteristics. In particular, there can be provided an objective lens having a numerical aperture that is as large as 0.75 or more and being suitable to be used for a high density recording/reproducing apparatus employing a laser wherein a wavelength of a light source is as short as about 400 nm. Further, sensitivity for decentering is made to be excellent, and aspherical aberration and coma can be corrected satisfactorily.

It is further possible to provide an objective lens which is suitable for a recording/reproducing apparatus wherein a thickness of a protective layer of an optical information recording medium is as thin as about 0.1 mm and a working distance can be small.

Disclosed embodiment can be varied by a skilled person without departing from the sprit and scope of the invention.